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Measurement of energy security in the electricity industry and its determinants: 12 Selected Latin American Countries

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Measurement of energy security in the electricity industry and its determinants: 12 Selected Latin American Countries

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Abstract

The Latin American region is well known for its wealth in terms of natural, mineral, and hydrocarbon resources. In addition, it represents a strategic geographical zone where international trade is growing as a result of markets' expansion. The involved nations have accomplished some socio-political as well as macroeconomic developments, which have been supported with the enforcement of democratization, regional integration, the adoption of responsible macroeconomic decisions, monetary and fiscal policies, and openness to free trade and private-sector participation. The region has shown stable economic growth despite the recent international financial and economic crises.

In this region, it is possible to find developing countries that are interacting in a sub-regional context with others that have a more advanced level of socio-economic development. For example, Mexico and Chile are members of the Organization for Economic Co-operation and Development (OECD), while Colombia and Costa Rica are aspiring to become members, and all of them are interacting with their neighbors. These special and dynamic characteristics differentiate this region from others around the world (Southeast Asia, Central Asia, the Middle East, and Africa) and offer more value for conducting research studies regarding economic and energy issues.

All these situations have drawn the attention of the world's largest economies to associate and cooperate in terms of bilateral investment. However, there is uncertainty about the security that can be offered by

these countries' domestic electricity industries. It is well known that most of the nations have potential for the development of energy projects at the resource and the power generation levels, but it is not clear whether their electricity industries can continue supporting fast economic growth and the development of new business in the zone. This insecurity was accentuated after the liberalization of their electricity industries.

The main focus of this research is to assess the performance of the electricity industry's supply chain in terms of energy security in 12 selected Latin American nations: Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia, Ecuador, Peru, Chile, and Argentina. We have considered an energy security area and a geographical region that have not yet been covered. With the support of the principal component analysis principles, we have transformed a set of simple and aggregated indicators into a set of relative indicators, which were evaluated under the basis of well recognized and accepted international standards as well as concepts from economic theory.

Through this process, it was possible to build a set of composite indicators represented as the supply security indexes along with the electricity industry's supply chain to study the influence of internal and external issues. Our results indicate that Chile, Colombia, Peru, and Ecuador are the most secure nations in terms of the security of the electricity supply. The outcomes for most of the studied countries are within the limits of a medium level of security. Currently, most of the countries in the South Latin American sub-region have a moderately high level of electricity supply security. The causes for the decreasing performance are the poor outcomes in terms of security in the different systems that compose their electricity industries.

Energy security in the electricity industry depends on the availability of energy resources as well as electrical infrastructure capacity. However, Chile, Guatemala and El Salvador, although are not fully rich in energy resources, have shown that insecurity levels can be improved by diversifying the number of suppliers as well as the nation's energy mix based on renewable energy resources. Regarding the performance of electricity generation and the electricity transmission and distribution systems, security depends on upgrading electrical infrastructures and operating under quality standards. With the failure to comply with standards in certain activities of a given system, the risk of failures and insecurity levels increase.

The studied Latin American electricity industries' performance, in terms of supply security, is susceptible to the influence of both internal and external factors. Our policy implications propose that governments are the key actors for adopting innovative decisions to strengthen energy security in the electricity industry. On the other hand, regulation is the tool for enforcing actions that aim to improve the industry's performance in terms of supply security. The implementation of an accurate management system in terms of resources development and import of commodities is required. The settlement of incentives for enticing investments to accomplish the development of new and large energy projects based on friendly energy resources is required, in addition to the establishment of robust and efficient electrical infrastructure capacities that respond to socio-economic demands. The establishment of energy conservation and demand-side

management programs, as well as control systems to improve security levels and reduce intensities, is necessary.

Keywords: Energy security; electricity industry supply chain; indicators for security of electricity supply; composite indexes; electrical infrastructure efficiency.

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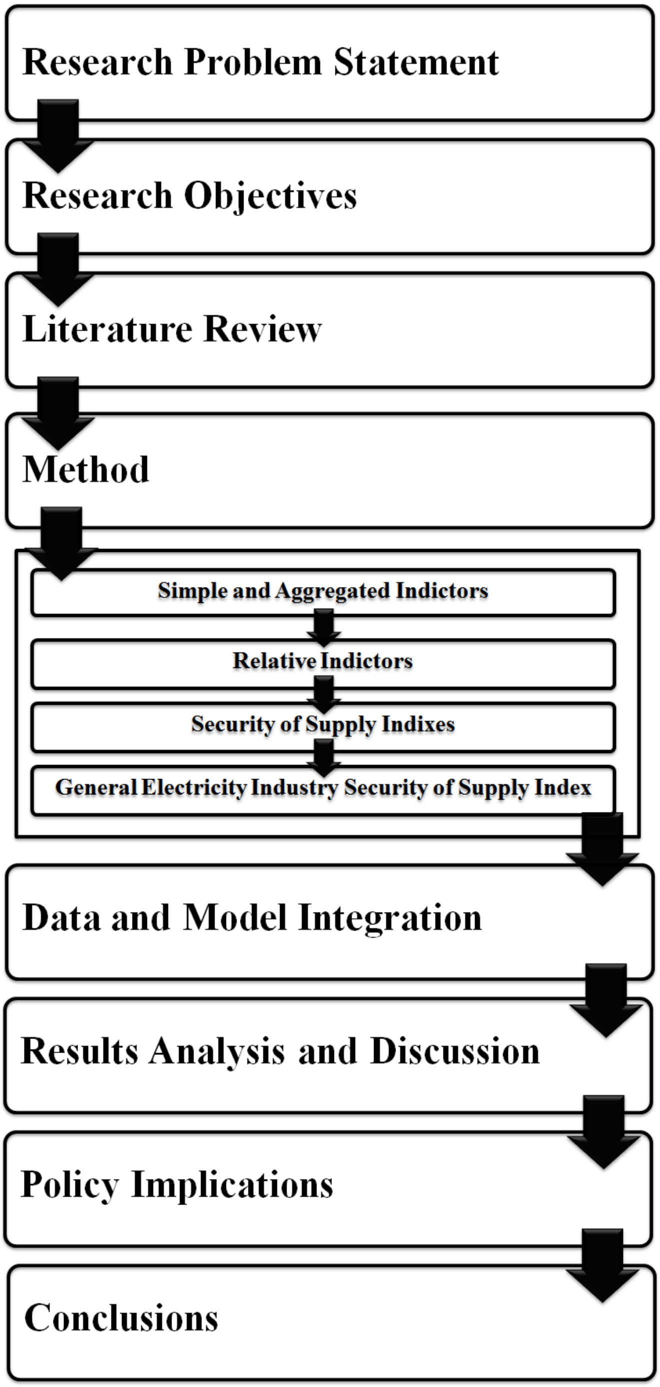
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List of Principal Abbreviations

In order of importance or relationships:

RSSSI	Energy Resources System Security of Supply Index
GSSSI	Electricity Generation System Security of Supply Index
TDSSSI	Electricity Transmission and Distribution Systems
EISSI	Electricity Industry Security of Supply Index
EI	Electricity Industry
ERS	Energy Resources System
EGS	Electricity Generation System
T&DS	Electricity Transmission and Distribution Systems
SOEs	State Owned Enterprises
RPR	Reserves to production ratios
ESIprice_regional	Energy Security Index Price Regional
ERID	Energy Resources Import Dependency
EM	Energy Mix Diversification
ELID	Electricity Import Dependency
RCF	Reserves Capacity Factor
IAF	Infrastructure Aging Factor
UftT&D	Utilization Factor of Transformer
UFplT&D	Utilization Factor of Power Lines
LfT&D	Technical and Non-Technical Losses Factor
PfT&D	Power Factor
χR1	Relative Indicator for the Reserves to Production Ratio
χR2	Relative indicator for the Energy Security Index
χR3	Relative Indicator for the Energy Resources Imports Dependency
χR4	Relative Indicator for the Energy Mix Diversification
χG1	Relative indicator for the Electricity Imports Dependency
χG2	Relative Indicator for the Reserves Capacity Factor
χG3	Relative Indicator for the Effective installed Capacities
χG4	Relative Indicator for the Infrastructure Aging Factor
χT&D1	Relative Indicator for the Utilization Factor Transformer
χT&D2	Relative Indicator for the Utilization Factor Power Lines
χT&D3	Relative Indicator for the Losses Factor
χT&D4	Relative Indicator for the Power Factor
KTOE	Kiloton of oil equivalent
PW	Petawatts
TW	Terawatts
GW	Gigawatts
MW	Megawatts
KW	Kilowatts
PWh	Petawatts per Hour
TWh	Terawatts per Hour
GWh	Gigawatts per Hour
MWh	Megawatts per Hour

KWh	Kilowatts per Hour
MVA	Mega-Volts Amperes
LNG	LNG Liquefied natural gas
SNG	SNG Synthetic natural gas
Mbbl	Millions of barrels
Gm^3	Cubic giga-meters or thousand million cubic meters
Mt	million tons
LACs	Latin American countries
MEX	Mexico
GTM	Guatemala
ELS	El Salvador
HND	Honduras
NIC	Nicaragua
CRC	Costa Rica
PNM	Panama
COL	Colombia
ECU	Ecuador
PER	Peru
CHL	Chile
ARG	Argentina

Chapter 1. Introduction

1.1 The electricity industry

To understand the present study, the basic concepts underpinning the characteristics of the electricity industry are described. Energy is transformed into electricity by various means. Rizzoni (2004, 853) indicated that a power plant can transform mechanical energy into electricity through the use of water, solar, wind, thermal, waves, tide, waste, wood, nuclear, and fossil fuel resources. These different resources compose the electricity industry's energy mix to produce electricity. The United Nations (2007, xxiii) has defined electricity production as "gross production, which includes the consumption by station auxiliaries and any losses in the transformers that are considered integral parts of the station included also its [sic] total electric energy produced by pumping installations without deduction of electric energy absorbed by pumping.".

Mexico's National Commission for Energy Efficiency (2013) stated that Electricity is transformed in different voltages through the use of substations and later is transmitted and distributed via cables and electric pylons. The power has the ability to be readily converted into any other form of energy with satisfactory performance, in addition to transport economic air networks. According to Guatemala's Instituto Nacional de Electrificación (INDE, 2013a), the units to measure the power are in terms of petawatts (PW), terawatts, (TW), gigawatts (GW), megawatts (MW), and kilowatts (KW). Electricity service plays a significant role in a society's economy since it is vital to achieve a certain standard of living and to cover certain daily needs at an affordable cost (Won, 2007).

An electricity industry is a set of all types of power plants, transformation substations, networks, distribution substations, and networks that are linked with the purpose of providing service for its customers (INDE, 2013b). Various systems exist inside the industry, i.e., energy resources, generation, transmission, and distribution. These systems can be owned and managed by either the state or private corporations or by both in conjunction. Institutions such as market entities are responsible for coordinating all transactions between the participating agents (AMM, 2013). The regulatory institutions are responsible for enforcing laws and regulations for governing the industry. Governing institutions are responsible for formulating policies and laws.

1.2 The Latin American region

1.2.1 Geological context

The Latin American region has a territorial range of 20,336,330 km2 with great ecological diversity, including variations from sea level up to 4,000 meters of altitude and pluvial rainfall ranging from 400 to 5,000 mm a year in a relatively small area. There are several mountainous systems with great ecosystem diversity and with endemic species and several neighboring orographic areas, such as: a) the Sierra Madre Oriental and Occidental mountain ranges that border Mexico; b) the Sierra Madre mountain range that runs through Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama; and c) the Andes mountain range, which crosses Colombia, Ecuador, Peru, Chile, and Argentina.[1]

It also has 15% of the world's oil reserves, mineral reserves, one-fourth of the world's arable land, and one-third of the drinking water. Most of the countries have gold, silver, copper, iron ore, tin, and hydrocarbons as major mineral resources. In addition, it is well known that this region has abundant hydro, solar, biomass, and geothermal resources that have not been exploited yet. All these vast resources provide opportunities to develop the potential of the region and to become a vital world player in supplying food, energy, and water. This wealth can be utilized to achieve economic growth by supporting industrial and commercial activities. The region has several sites where it is feasible to build hydro power plants.[2]

1.2.2 Economic and socio-demographic contexts

The countries in the region have experienced sustainable economic growth with an annual average of over 4% during the past decade. Compared with other nations in Africa, Central Asia, and Southeast Asia, most Latin American countries have improved their income per capita and established trustworthy political and economic frameworks. They have supported their development with democratization, responsible macroeconomic decisions, regional integration, and suitable monetary and fiscal policies, as well as accessibility to free trade and private-sector

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[1] Carlson, Fred A. 1952. "Geography of Latin America." New York, United States: Prentice-Hall, Inc.

[2] United Nations Economic Commission for Latin America and the Caribbean (ECLAC). 2004.

participation. The Latin American region has shown economic stability and notable capabilities to recover from the effects of the international financial crisis of 2009.

Brazil is the sixth largest economy in the world, with a strong domestic market and abundant natural resources. Although business optimism is high in Brazil, there are other emerging economies, such as Argentina, Peru, Chile, Colombia, and Mexico,[3] Across Latin America, there are strong prospects for increasing investments in the energy business over the next decade. Colombia is the fourth largest economy in Latin America and might be worth considering, too. The region is rich in natural resources, and analysts predict strong growth in the wake of improved security, an increase in mining activity, and strong commodity prices. Mexico is one of the top five global emerging economies. It offers a large internal consumer market and, with its closeness to the U.S., it is an attractive alternative to China as a manufacturing base.[4]

In addition, the Mesoamerican area, which spans from southern Mexico to northern Colombia, is considered appealing since it has a strategic geographical position in the continent. The Panama Canal is located in this sub-region, and there are plans to develop two or three more alternative routes to interconnect and strengthen trade activities between Asia and the Americas. For example, the United States industrial zone ranges from the Midwest to the East Coast, and its location requires that goods be moved through the Panama Canal or over the Rocky Mountains. In both cases, the freight costs are still high. It is necessary to develop

[3] http://espanol.doingbusiness.org/press/press-releases/2011/press-release-lac
[4] http://www.stratfor.com/

basic infrastructures in the Mesoamerican area to support economic growth in the region overall.

Latin America has almost 570 million inhabitants and some positive socio-economic factors, such as a common language, similar cultural values, and a growing middle class.[5] The Central Asian nations might be comparable in terms of language and cultural values, but they lack logistical opportunities due to being landlocked, and the political and socio-economic developments achieved by the different Latin American nations is another difference. The different sub-regions that comprise the Latin American region have been modernizing their basic infrastructures. Developments have been made in roads, maritime ports, airports, telecommunications, power plants, and substations. Around 40 million people emerged from poverty due to governmental programs that aimed to reduce poverty and improve labor conditions.

This region has countries that share a common language (Spanish) as well as cultural characteristics because most of them are former Spanish colonies.[5] However, in comparison with other regions around the world; this zone offers an opportunity to study nations with a variety of nuances. On one hand, there are countries that are rich in resources and territorial range, as in the cases of Venezuela, Brazil, Mexico, Colombia, Peru, Argentina, Ecuador, Bolivia, and Chile. On the other hand, there are small countries that do not have significant potential resources, such as the Central America nations, Uruguay, Paraguay, Guyana, and Suriname.

It is possible to find developing countries that are interacting in a sub-regional context with others that have a more advanced level of socio-

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[5] http://undpress.nd.edu/book/P00223

economic development. For example, Mexico and Chile are members of the Organization for Economic Co-operation and Development (OECD),[6] while Colombia and Costa Rica are aspiring members, and all of them interact with their neighbors.[7] These are special characteristics that differentiate this region from others around the world (Southeast Asia, Central Asia, the Middle East, and Africa) and offer more value for conducting research studies regarding economic and energy issues.

International trade and business are becoming increasingly important to many Latin American nations. Most of the states have subscribed to free trade agreements (FTAs) with the European Union, the United States, and some Asian countries. The Trans-Pacific Strategic Economic Partnership Agreement (TPSEP or P4) is a multilateral FTA that aims to liberalize the economies of the Asia-Pacific region. It already involves two Latin American countries and has increased the interest of others in joining them. In the North American zone, Mexico is interested, while in the Central American zone, Costa Rica is interested, as is Colombia in the South American sub-region.

In 2012, the World Economic Forum on Latin America was held[8] in Puerto Vallarta, Mexico. This proved to be a gateway to national marketing to attract foreign capital investment for the development of manufacturing plants and supply of services. During the forum, leaders and investors from both Latin American countries as well as from developed countries around the world gathered. Both leaders and investors are aware

[6] http://www.oecd.org
[7] http://www.eclac.cl
[8] http://www.weforum.org

of the advantages offered by the region for the development of new business to strengthen the investment ties.

There is environment for doing business in the selected Latin American nations since they have made efforts to strength the rule of law.[9] However, there is uncertainty about the security that can be offered by their domestic electricity industries. Actually, it is well known that most of the nations have potential for the development of energy projects at the resource level as well as at the power generation level,[10] but there are doubts regarding whether the different systems that compose their electricity industries can support economic growth and the development of new productive activities. This insecurity was accentuated after the liberalization of electricity industries in the region.

Compared to other geographical areas and countries around the world, Latin American countries contribute minimally to the development of scientific research in the field of energy-related industries.[11] There is a lack of detailed information about energy security issues in the region. There are single reports about performance carried out by the Economic Commission for Latin American and the Caribbean (ECLAC)[12] and the Organization of American States (OAS).[13] In terms of energy security, their investigations generally have been comparative studies in other regions and in the international energy markets, which have not been able

[9] http://espanol.doingbusiness.org
[10] http://temp2.olade.org/informe.html
[11] http://www.farq.edu.uy/biblioteca/files/2011/10/Publicaci%C3%B3n-de-art%C3%ADculos-cientif%C3%ADcos-Presentaci%C3%B3n-de-Elsevier.pdf
[12] http://www.eclac.org/publicaciones/xml/3/32123/lcl2828e.pdf
[13] http://www.oas.org/U.S.DE/Spanish/Documentos/EnergySecurity_SPA.pdf

to address the real problems affecting the zone and specific industries, such as the electricity sub-sector.

1.2.3 Developments of the electricity industry

According to the Solar Foundation and the Inter-American Development Bank (IADB; 2002), the electricity industry in this region had its origins in the private sector during the 20th century. However, after World War II, the national governments started acquiring and nationalizing their facilities and adopted a vertical integrated monopoly model through the establishment of state-owned enterprises (SOEs). From the 1950s to the 1990s, according to Williams and Dubash (2004), the expansion of the electricity industry was part of central planning. The authors also proved that these nations have undertaken these actions with the aim to encourage the growth of their economies and accomplish missionary activities such as rural electrification.

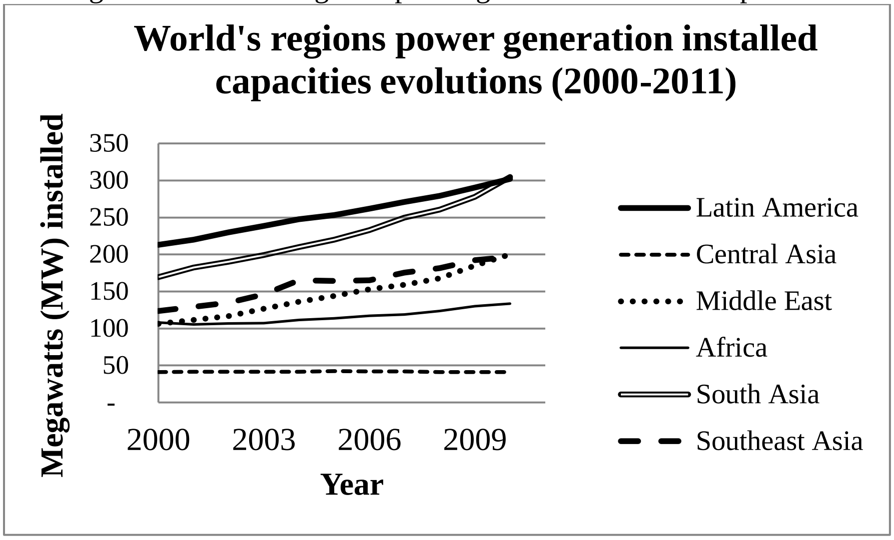
During the past three decades, several electricity industries in the Latin American region were deregulated because SOEs were not efficient to ensure the continuity of the electricity supply (Millan et al., 2001). Investments, competition, technological innovation, and the introduction of better managerial practices were the main justifications raised to end the inefficiencies experienced under the monopolies (Andres et al., 2006). Additionally, the International Monetary Fund (IMF) as well as regional development banks recommended to governments the privatization of some SOEs involved in railroads, telecommunications, and electricity. The recommendations were intended to increase the nations' international monetary reserves and reduce indebtedness level.

The liberalization of the electricity industry as well as other areas was possible as these nations moved from dictatorships or instable political regimes to more stable democratic systems. During this period, these nations were under a neoliberal influence. In fact, the recommendations of the IMF were echoed by the government authorities, and privatization processes were enforced (Research Center on Economic and Political Community Action [CIEPAC]; 2002). Based on these reasons, the entrance of private investors was allowed in the different Latin American electricity industries. These actions also led to the development of new institutions for regulating and operating the electricity market under a competitive model.

Several nations sought to attract private investments to cover in the short and mid-term the necessities of an available infrastructure for producing electricity and to increase the electrification coverage rate (Aldana et al., 2011b). However, these changes in the industry's organization increased the prices of electricity service. Currently, the electricity industry is organized and governed under an almost completely privatized model.[14] The regulatory framework of the industry is based on a competitive market model, at least for the electricity generation system. It is also expected that electricity transmission and distribution systems can improve their performance. Figure 1.1 shows the evolution of installed capacities in several regions around the world.

[14] Asociación Iberoamericana de Entidades Reguladoras de la Energía (ARIAE), http:// www.ariae.org

Figure 1.1 World's regional power generation installed capacities



Source: Energy Information Administration (2013)

On the other hand, countries such as Mexico,[15] Honduras,[16] Costa Rica,[17] and Ecuador[18] have organized, owned, and managed their electricity industries through a state monopolistic model. Over time, all the efforts undertaken to reform the sector have failed because of political and social resistance as well as a lack of government capability to implement policies (von-der-Fehr and Millán, 2004). Ecuador re-nationalized the industry due to changes in its political structure toward a socialist model in the 21st century (Rose and Joskow, 1990), and private participation was allowed only in the electricity generation system through specific service contracts.

[15] http://www.cre.gob.mx/
[16] http://www.cne.gob.hn/
[17] http://www.aresep.go.cr
[18] http://www.conelec.gob.ec/

The hemispheric power integration has become the focus of cohesion and development in the Latin American region. For more than two decades, efforts have been made to interconnect these nations, but only at the VI Summit of the Americas (2012), with the signing of Americas Connect 2020–2022, was significant political progress made. The paper presents the proposed hemispheric electrical integration, which shows the dynamics of the electricity market, progress in sub-regional integration agreements, and challenges left by the VI Summit. Furthermore, most of the countries are interconnected electrically, as shown in Figure 1.2.

Figure 1.2 Latin American electrical bilateral interconnections

Source: Comisión de Integración Energética Regional (CIER; 2011)

1.2.4 Importance of Latin America

To support economic growth and consumption demand, nations in the Latin American region have increased their installed capacities at the generation level through the involvement of private investors over the last twelve years (Aldana et al., 2011b). In addition, through bilateral electrical interconnections the under studied nations are trading electricity and managing their surpluses or deficits. However, the different systems that compose the domestic electricity industries in these nations have been facing unstable performance in the terms of the continuity of the electricity supply. These situations might be influenced by internal and external factors. It seems that demand requirements are greater than the accomplished developments, and the ability to achieve sustainable social-economic development for the next decade is still unclear in this region.

In addition, since deregulation processes were accomplished, the performance of the electricity industries has not been assessed in terms of supply security. It is not clear whether the nations are ready or whether they are taking the necessary actions to continue supporting the expansion of new business, economic growth, and regional integration activities. The development of regional electricity markets will require the execution of large energy projects, but these have been delayed due to social and environmental concerns. In some states, electricity service prices have increased, and it is not clear whether these situations are favorable for the improvement of electrical infrastructures.

The energy matrixes before deregulation were mostly based on renewable energy resources (hydro power), but after this process, the nations became dependent on the use of hydrocarbons to produce electricity (Aldana, 2011c). This situation has affected electricity service prices because of the volatility of the prices of energy commodities in the international markets. The governments have been trying to promote the development of several hydro power plants to shift the current energy matrixes to ones based fully on renewable energy resources. However, the governments and private investors have met social resistance as well as adverse environmental conditions (Aldana, 2012b). In addition, the performance of these industries has not been evaluated in terms of supply security after deregulation processes to determine whether these actions were the proper ones.

Large hydroelectric projects are attractive in the region due to their potential, but they can generate a negative impact on ecosystems and on the regional topography. Renewable energy projects are of interest today with respect to the effects of global warming, especially in those Latin American countries adjoining the Pacific Ocean, which are affected by natural phenomena such as ‘El Niño’ and ‘La Niña’ (Aldana, 2011a).
Hydroelectric dams usually have some years with plenty of water and others with a scarcity, which limits their operation. Over the years, a great number of hydrological reservoirs may suffer from excess sediment accumulation as a result of mudslides on hillsides and mountains.

Over the past ten years, public referendums have been held in the villages to show the governments their rejection of the development of mega hydroelectric projects (Aldana, 2012b). This negative response is a result of the high prices of electricity service since it has become obvious that companies participating in the electricity sector in the area of power generation are accumulating substantial profits from their business. The communities' demands to stop the development of new energy projects are supported under the provisions established by International Labor Organization Convention 169,[19] which has been ratified by the Latin American governments.

There is no information on whether the different sub-regions and nations that compose the Latin American region are secure in supplying electricity service without interruption and at affordable prices. In addition, it is necessary to set determine whether the nations can continue supporting their economic growth and the expansion of new business during the next ten years as a result of foreign direct investment (FDI). According to UNCTAD reports,[20] Latin American countries have been the recipients of more FDI than other regions. In fact, the selected nations have been the largest recipients of investments for the development of renewable energy projects in comparison with other sub-regions around the world.[21] The recent economic crisis in the Eurozone drove several investors to move to Latin America due to their macroeconomic stability and potential for settling new business. For potential investors, it is important to know whether a given nation can meet their electricity consumption requirements for the establishment of new businesses.

We selected Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia, Ecuador, Peru, Chile, and Argentina because it is a region that has economic importance and has not

[19] http://www.americasquarterly.org/node/2439
[20] UNCTAD, World Investment Report (2013; 39, 44, 49, 53, 57, 63).
[21] Renewable Energy Policy Network for the 21st Century, Renewables Global Status Report (2013; 59).

yet been studied in terms of energy security. In addition, a variety of political, social, and economic developments enriched this research. The different sub-regions are developing common regional electricity markets, and this situation is helpful in studying energy security in the electricity industry. There are strategic geographical areas as well as high potential for the development of energy projects and thus support for economic growth, but it is required to determine whether the selected nations are secure in supplying electricity service without interruption and at affordable prices.

Other reasons to conduct research regarding energy security in the electricity industry of Latin American countries include the fact that these nations are still undertaking the development of basic infrastructures. It might not be interesting to conduct an investigation in highly developed states such as the United States, Canada, Japan, Korea, Australia, New Zealand, and European nations, as they have succeeded in providing electricity to their domestic regions and have already established considerable amounts of installed capacity. In addition, developed nations are well known for operating under accepted international technical standards and efficiency principles from economic theory. For the aforementioned reasons, it is interesting to consider the Latin American region, where we might have a chance to find situations and policies that need to be improved.

Countries in Africa, Central Asia, the Middle East, and Southeast Asia may offer another opportunity to carry out this type of research but on an individual basis because these nations are limited not only in terms of data availability but also in having a common language. Furthermore, in these regions, the countries do not share the same developments reached by Latin American countries, which have deregulated their electricity industries and bilateral electrical interconnections and where the geography is more favorable since they are not landlocked states (with the exception of Bolivia), and they are not located on an archipelago. Our cases have access to both the Pacific and Atlantic oceans.

1.3 Conceptualization of energy security

Energy resources can be transformed into either fuel or electricity through the use of different technologies (Aldana and Heo, 2012). Both commodity fuels and electricity play a significant role in the society's economy since they are vital to achieve a certain standard of living and cover certain daily needs. Due to its importance, the need to ensure the security of the energy supply has drawn the attention of political leaders with a strong impetus since California's electricity crisis. It has been addressed within their policies with the objective to strengthen the nations' economic growth and provide sufficient energy by means of combustibles and electricity. The negative effects brought by electricity shortages and high prices, increased concern about securing energy systems through defining, identifying and measuring threats.

Jansen, Van Arkel, and Boots (2004) defined long-term energy supply security as the need to "ensure [the] meeting [of] ex ante demand for energy services at affordable prices." On the other hand, regarding energy commodities, the European Union of the Electricity Industry (EURELECTRIC; 2006) has defined the security of electricity supply as “the ability of the electrical power to provide electricity to end-users with a specified level of continuity and quality in a sustainable manner, relating to the existing standards and contractual agreements at the points of delivery.” In both cases, as well as in other 27 different studies regarding the development of concepts and measurements of energy security, the main concern is the availability and continuity of the supply of primary energy resources as well as energy commodities such as fuels, heat, and electricity.

Definitions of energy insecurity include the one developed by the IEA (2007), which considered that it “stems from the welfare impact of either the physical unavailability of energy, or prices that are not competitive or overly volatile.” Furthermore, Gnansounou (2008) considered that it is a state that happens when a specific energy system is unable to overcome negative situations affecting the proper delivery of energy commodities or services to the final customers. The former study took into consideration as factors influencing the insecurity of the energy supply the physical availability and the price component, while the latter study was concerned with finding factors belonging to a specific energy system and the main reasons for disruptions in the delivery of energy commodities to the end users.

1.4 Electricity industry and energy Security

In ancient times, the machinery used in the production of goods or the provision of services was driven by manual processes. As technological advances were made, the automation of productive processes took place by means of electricity (Usher, 1988). The electricity industry became the pillar that supports the development of human and economic activities. The electricity industry is important in terms of energy security because the energy supply must be guaranteed without interruption and at affordable prices (Helm, 2002).

The economic effects of the electricity industry are reflected in the level of wealth that a nation can achieve through productive activities with the supply of energy without interruption and at affordable prices. The social effects include the level of satisfaction and development that the inhabitants of a society can reach due to the use of electricity to meet daily needs as well as to maintain a certain standard of living. The environmental effects are reflected in the degree of conservation of natural ecosystems without altering the quality of life of those who live close to them despite the fact that the exploitation of energy sources has relocated them far from their original homes.

Electricity is essential since it is used for residential, industrial, agricultural, and commercial purposes. Furthermore, it also seems to be the future for the transportation industry due to technological improvements and trends in this sector. For any country, keeping the cost of electricity cheaper for the main export-oriented industries can facilitate greater competitiveness in the international market. Electricity consumption and domestic production are fundamental in determining a country’s electricity self-sufficiency (Jamasb, Newbery and Pollitt, 2004). In the electricity markets, energy security is important in terms of productivity level, pricing, marginal reserves, and cost efficiency.

The electricity sector has a significant impact on a nation's economic, social, and environmental scope, and for these reasons, it must be protected from failure and from the risks that affect the energy supply. The electricity industry is important in terms of energy security because it is sensitive to disruptions in the supply of the required commodities as well as unexpected price fluctuations and their negative effects on social, economic, and environmental factors. Additionally, because it is a basic service that has to meet demand requirements in real time, its security must be ensured (Schwenen, 2011).

The main concern of energy security for this particular industry is to guarantee the availability and accessibility of sufficient amounts of power and energy to secure delivery in accordance with demand requirements (National Energy Education Development Project [NEED]; 2011). Energy security for the electricity sector must be guaranteed by making the required investments for building the electrical infrastructure both to cover the increasing demand and to modernize old infrastructures that decrease performance (EURELECTRIC 2006; Badea et al., 2011).

Due to its importance, the electricity industry is the best scenario to apply policies, laws, regulations, and standards, as well as to take actions to secure the supply of this vital service at any time and at competitive prices. It is only through actions that ensure supply security that the electricity industry can support human activities, economic processes, and a nation's social and economic development. Furthermore, it is only in this scope where it can find the required protection against any type of risk that can diminish its performance to the detriment the welfare of a society and its economy.

Most electricity industries worldwide operate under a competitive environment that is not exempt from the effects created by risk factors within the micro and macro industry environment (Fisher and Rothkopf, 1989; Stoner, Freeman and Gilbert, 1995; Hill, 2007; Kolos and Ronn, 2008). The electricity industry cannot manage some risk factors because of their own intermediary nature and because some of these threats are beyond the limits of their operation (Bielecki, 2002). In most cases, they do not own the energy feedstocks that are employed in producing electricity. For the aforementioned reasons, electricity industries are susceptible to the effects instability in policies, regulations, market conditions, economic issues, and environmental conditions (Ringel, 2003; Jafar, Al-Amin, and Siwa,r 2008; Vivoda, 2010; Azevedo et al., 2010).

1.5 Definitions

To understand the present thesis, we aimed to expand the concept of energy security to the electricity industry. Security is synonymous with certainty and guarantee, and it can be defined as the state in which a specific status can be reached or at least kept constant. Security provides certainty about the well-being of individuals and societies (Aldana, 2010). This status can include peace, food provision, health, wealth, living standards, the provision of public services and goods that support economic activities, etc. Human beings and societies by nature try to guarantee coverage without interruption of daily activities and to support productive activities that are a prerequisite to improve or at least maintain their current status.

Energy security is a multidisciplinary concept from which emanates a set of policies, laws, regulations, and settled standards, as well as the actions that must be undertaken to supply any kind of energy commodities as the case of electricity and in accordance with its demand (Aldana and Heo, 2012). It has a wide range of interactions with other related disciplines. Since security is synonymous with certainty, energy security refers to the proper management of the internal and external factors that may affect the optimal performance of any sub-sector of the energy industry of a nation. Optimal performance means obtaining the required resources and the infrastructure for the provision of any kind of energy commodity.

Energy security in the electricity industry involves policies, laws, regulations, standards, and the actions that must be undertaken to ensure the flow of sufficient amounts of electricity throughout the electricity industry's supply chain[22] until it reaches the final customers without interruption and at affordable prices in accordance with the economic capacity of a nation's inhabitants (Aldana and Kim, 2013). The continuity of supply in delivering the service, throughout the system, must be guaranteed by means of evaluating the performance of each sub-system. Energy security in the electricity industry must be achieved through identifying threats that affect the continuity of supply and self-sufficiency.

Security of the electricity supply is linked significantly with the standard of living and the objectives of wealth and prosperity that a

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[22] "Supply chain management." Encyclopaedia Britannica Online Academic Edition. Encyclopædia Britannica Inc., 2013. Web. 03 Dec. 2013. A supply chain consists of steps in which material is transferred from one place to another in the value chain; instead of merely transferring material, we add certain value to it.

country or society is trying to pursue (Aldana, 2010; Aldana and Heo, 2012). This intimate relationship is created by the need to utilize this commodity at least to maintain the status quo in the standard of living or in trying to increase prosperity. The desire to achieve stability is generated by the social, political, economic, technological, and natural environmental factors that may affect a country's energy resources. The purpose of this concept is to ensure the present and future supply of electricity, which is used for the exploitation of any economic activity within a society as well as to meet individual demands for well-being.

1.6 Organization of this research study

Electricity plays a significant role for any society since it is vital to achieve a certain standard of living and to cover certain daily needs (Asif and Muneer, 2005). Furthermore, the supply of electricity without interruption is essential in most productive areas of the economy. Obviously, it is essential for the whole society; for example, hospitals need to provide specific services that require the use of electricity, and water pumping is used for the irrigation of large-scale agricultural processes. However, according to the World Bank (2010), in Guatemala, the price of the electricity is the highest in the Americas, and this has affected the development of small and medium-sized enterprises, impeding the national economic growth.

The electricity industry has become a business, especially due to the deregulation and the globalized economic processes. The business is susceptible to the effect factors associated with firms' micro-environment as well as by factors associated with firms' macro environment (Stoner, Freeman and Gilbert, 2005). The problem of supply security in the electricity industry concerns the unstable performance of the different systems that compose the domestic electricity industries in the selected Latin American countries in terms of the continuity of the electricity supply. The industries have been facing electricity shortages, vulnerabilities regarding the supply of energy commodities, and backwardness in increasing the countries' installed capacities due to the nature of demand as well as the influence of other internal and external factors. It seems that demand requirements exceed the developments accomplished, and the ability to reach sustainable social-economic development as well as to continue the establishment of energy projects is still unclear in this region over the next decade.

Our motivation for this research study came from the fact that, even though more than 750 investigations have been done regarding concepts and ways to measure energy security, no prior study has dealt with supply security in the electricity industry by considering its supply chain.[23] Most investigations have focused on energy resources, especially fossil fuels, nuclear power, and the mitigation of pollutant emissions. Furthermore, they have evaluated developed and industrialized regions. However, we believe that it is necessary to evaluate emerging economic regions such as Latin America, where foreign investments are being made because of the benefits offered by the zone, as well as because of economic deceleration and crises in other areas of the world.

[23] http://www.sciencedirect.com/science?_ob=ArticleList

We aimed to develop a methodology to assess energy security in the electricity industry. We have determined that it is possible to improve on prior approaches, which were useful but limited to assessing energy security only in the energy resource system. Our intention was to expand on these approaches and apply the result to the whole electricity industry supply chain. We aimed to construct a security index method for measuring supply security in the electricity industry's supply chain. All of this is a counterpart initiative to the composite vulnerability indexes employed previously by Gupat (2008), Gnansounou (2008), Cabalu (2010), and Badea et al. (2011).

We aimed to consider technical issues and concepts from economic theory that have been avoided before because the lack of consensus among scholars and technicians form the electricity industry. This effort was supported through consideration of principal component analysis principles. Also, we considered standards and concepts from economic theory to manage the marginal values of relative indicators. Our decision fits with security considerations because these attempt to prescribe basic functions and reach suitable safety levels by mitigating risks. With these foundations, in our index method, it was not necessary to consider other types of weights because we want to be more supply-objective-oriented. We intended not to allocate less reasonable values into the approach that can compensate inefficiencies in failing to comply with standards in certain activities of a particular system. The success of our model depends on outlining the threats as well as accurately defining their importance based on the available literature and data.

Our methodology can contribute to the establishment of security levels for the overall electricity industry and at the level of different systems. This is a specific distinction of our research in contrast with that of others. With the results obtained from applying our methodology, it can be determined whether the electricity industry of a given nation is able to support productive economic activities as well as to establish new business related to the electricity industry in deregulated markets. Furthermore, we aimed to propose quantitative and graphical models to provide a more comprehensive understanding of the threats affecting electricity supplies by studying the whole industry's supply chain. This model can be employed in future analyses in other sub-sectors that compose the energy industry, as in the cases of hydrocarbons and minerals. Our methodology is not limited to a specific geographical context or to the use a specific number of indicators. It still can be expanded if data are available.

For the aforementioned reasons, the following research questions are raised: which of the 12 selected Latin American countries exhibits the best performance in terms of supply security in their electricity industries' supply chains? What methodology can be applied for measuring energy security in the electricity industry's supply chain? Which are the internal and external factors that affect the electricity industries in the countries under study? What are the factors that can solve negative situations affecting the industries' performance?

Our research objectives are as follows: to establish the performance of the 12 selected Latin American countries in terms of supply security in their electricity industries' supply chain; to account for factors influencing the electricity industries in the countries under study in terms of supply security; to develop a proper methodology that can be used to measure supply security in the electricity industry's supply chain; and to develop policy implications that can contribute to solving negative situations affecting the industries' performance. Based on these objectives, we expect to contribute in determining security levels and which nations have more potential to continue supporting the expansion of new energy business in Latin America. Furthermore, we aimed to develop a methodology that can be used to evaluate the performance of the electricity industry's supply chain.

In our method, we have employed a set of simple, aggregated, and relative indicators to build indexes for assessing the electricity industry's supply security. This approach is helpful in identifying the factors influencing an electricity industry's performance. We have applied and expanded the methodologies employed previously by Gupta (2008), Gnansounou (2008), Cabalu (2010), and Badea et al. (2011) throughout the electricity industry's supply chain to assess supply security.

It might be a limitation t that most of the nations under study deregulated their electricity industries during the 1990s and most of the available statistical information has been collected since 2000, when the electricity industries fully entered the digital era and Internet access was diffused. There were limitations in accessing the information of nations such as Brazil, Venezuela, Bolivia, Paraguay, Uruguay, Belize, Guyana, and Suriname, so they have been excluded from this research. In conducting this study, Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia, Ecuador, Peru, Chile, and

Argentina were selected. These nations represent more than 50% of the Latin American region.

However, our supply security index models are not limited to employment in the assessment of energy security in the electricity industries of other countries or regions around the world. The model can be adjusted with the use of more or fewer indicators. These can be fitted into the relative indicators and indexes in accordance with the availability of data, which might be a limitation in terms of accessibility because of language, time, or market structures. These are common limitations in making international comparisons. In our case, we found that, in countries such as the United States, data must be obtained from several internal regional electricity markets as a result of the nation’s federal structure. For the aforementioned reasons, we selected the 12 Latin American nations because the data availability, accessibility, and timing suited our research interest.

This research paper covers the period from 2000 to 2011, for which most data are available for the selected indicators. Some researchers, such as Baca (2004, 81), have stated that at least 10 years is required to analyze the changes and effects in some areas under study. The scope of the study is a qualitative-quantitative investigation. The theoretical framework is an analysis of the previous literature regarding energy security. The arguments are supported with statistical data as well as information disclosed from governmental agencies and previous research studies.

This dissertation consists of seven chapters that include the support of various sources; some of them were originally written in English and

Spanish language, and the latter have been translated by the author. Chapter one contains the introduction that addresses the concepts, research problem statement, and objectives of this study. Chapter two presents the basic theories of energy security. This chapter contains an analysis of related previous literature regarding energy security. It introduces the reader to the different concepts and methodologies that have been developed previously to measure energy security. Finally, it emphasizes what has not been covered yet, our contributions, and how our study is different from previous ones.

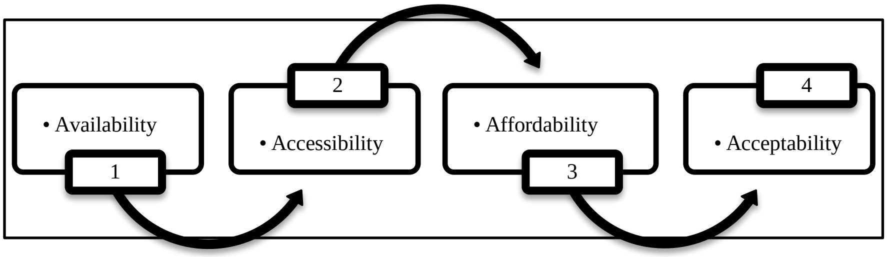
Chapter three starts by presenting our own definition of "energy security" for the electricity industry. Then, we proceed with a description of our supply security index model. Chapter four presents the data and the limitations we encountered in obtaining it, the theoretical framework for selecting indicators, and the integration of data into the model. Chapter five shows the calculation, the achieved results, and an analysis of the factors influencing the security of electricity supplies. In this chapter, we establish security levels for each system and for the overall electricity industry in each of the nations under study. Chapter six provides the policy implications to address negative situations and improve security levels. Finally, chapter seven provides the overall conclusions.

Chapter 2. Literature review

Energy security encompassed four dimensions according to Kruyt et al. (2009). These areas are availability, accessibility, affordability and acceptability. According to the theorists, in these scenarios different indicators for measuring the degree of energy security of one nation were located. Availability referred to the existence of energetic resources as well as the proper infrastructure for supplying energetic product and services. Furthermore, this term includes, by its own nature, the provision of the energetic commodities at any time and without interruptions (IEA, 2007). Technical issues are included under this scope. Accessibility referred to the capability to obtain these feedstocks without disturbances.

Affordability regarded to access these energetic commodities at reasonable prices, while acceptability referred environmental and social issues because energy projects should not produce environmental degradation or conflicts. These measurements were developed previously by various researchers and institutions and later on they were adjusted in order to measure energy security. The vast majority of indicators aimed to evaluate primary energy resources. This was because in the case of electricity which can be generated from a wide range of energetic commodities and for the foregoing reasons it was strictly related with the energy industry from which these feedstocks come.

Figure 2.1 Areas for measuring energy security



Source: Kruyt et al. (2009)

In the other hand Sovacool (2011a-c) employed a generalized qualitative approach in which the authors had emphasized five dimensions for measuring energy security such as availability, affordability, technology development and efficiency, environmental and social sustainability, regulation and governance. For the researchers availability was the ability to count with the necessary energy resources as well as the required infrastructure to transform these into energy commodities for satisfying necessities. Affordability accounted the access at that energy resources and commodities at lower prices as well with stability. Technology development referred to the ability to recoup energy systems from failures as well as interruptions. Sustainability accounted the competence to protect environment from activities related with the exploitation of energy activities. Finally, regulation referred to the ability of policy makers to enact recognized and effective legal instruments for regulating energy activities and others associated with them.

There were eighteen components established for assessing energy security in accordance with each dimension. Although of these categorizations, the indicators were not well classified according to the energy sub-sector which they belonged to. In another way, the indicators seemed to be scrambled. In addition most of the indicators did not reflect the way of making the measurement. However, this was one of the most complete studies about measurements for energy security. If these indicators were properly classified, in accordance with the energy sub-sector by including their metrics, collecting data for assessing a specific case, it would have been possible to assess energy security through an empirical way. The indicators were a clear reflection of the factors that can influence negatively or positively the performance of a specific energy sub-sector. These can be ordered also as the elements which can be controlled and cannot be controlled by humans, and were located inside the electricity industry micro-environment as well as macro environment.

The electricity industry is susceptible to be affected by distortions on the supply prices of primary energy resources as well as negative effects on climate change. In addition, it has strong influence over the optimal performance of an economy. Due to these close relationships that exist, an inevitable necessity for securing the provision of these energetic commodities in order to keep producing electricity and support the different economic activities of a nation. This part of the research presents the indicators for measuring energy security in accordance the dimensional classification made by Kruyt et al. (2009) as well as most of the indicators proposed by Sovacool (2011a,b,c) which has relationship with the electricity industry.

2.1 Energy security in terms of availability

2.1.1 Resource estimates

Observation and inventories were the traditional way to quantify resources in the past (Freeman, 2003). Brown, Gillespie and Lugo (1989) proposed a method for estimating biomass of tropical forests based on regression equations. The biomass from forests can be employed commercially as the one that was employed for electricity production. The approach allowed estimating aboveground biomass of individual tress as a function of diameter at break height, total height, and wood density. However, Lu (2006) indicated that since technological developments have been reached, especially in the information technologies field, sensed data has become in the primary resource for biomass estimation. The main instruments which allow estimating biomass are optical sensors, radars, and geographic information systems. Thus instruments have more precision on forests with high diversity structures of trees due to provide image textures which improve biomass estimation performance.

The technological advancements reached in the field of information technology have led that most of the energy resources can be estimated through employing devices, software and parameters. Estimations are commonly modeled in wide range of geographical zones and structures in order to determine energy resources' availability and potential. According to Kruyt et al. (2009) the simple indicators comprehended resource estimates, which account proved existences of energy resources and it is the first hand direct indicator that can be obtained from existence reports. The resources can be classified and quantified. The sum of all resources available in a specific country integrates the total resources estimation. Finally, by dividing the total amount of each resource into the total resources estimation provides the share for each resource.

2.1.2 Reserves and production levels

According to Cavallo (2002) the reserves and production levels can be measured by a simple indicator called the reserves to production ratios, which provides criteria about the time of production left at current production levels. It was a ratio indicating the residual duration of an energetic resource. The ratio was expressed in terms of years. It was used in predicting the expectations on utilizing a resource and to establish a project life. It can be used for any other type of natural resources once they have been estimated; however, it was mainly employed for fossil fuels. For calculating the reserves to production, ratios were required to take into account the proven reserves of any specific energetic resource. It can be at the end or at the beginning of the year for a specific country or region. The proven reserves of any specific energetic resource were divided into the total consumed amount of that specific energetic resource in an explicit year (Feygin and Satkin, 2004).

Table 2.1 Resources reserves

Measurement	*Metric Formula*	*Acronyms' Meaning*
Reserves to Production Ratios (RPR)	$RPR = \chi_i \div \sum\chi_{in}$	χ is the amount of proven reserves *i* is a specific energetic resource $\sum\chi_{in}$ total amount consumed for a specific resource in the year *n*

Source: Feygin and Satkin (2004)

2.1.3 Access to primary energy resources

The Union of the Electricity Industry (EURELECTRIC; 2006) developed a paper based on a qualitative analysis which integrated the indicators for measuring the outcomes produced by the electricity industry. There were six indicators in common for measuring the short and long-term security of electricity supply. Access to primary fuels for the long-term took into account dependence in oil prices, geopolitical instability, changes in energy demand, diversification, acceptance of nuclear energy, dependence on natural gas and hedging the risk on natural gas (Costantini et al., 2007). For the short-term this indicator considered access to local gas networks, and availability of renewable energy resources. The second indicator intended to measure the outcomes of the generation system.

For the long-term it considered the country's installed power capacity, placement of future power plants, environmental constraints (Asif and Muneer, 2007; Weisser, 2007), public acceptance of future projects, and siting issues. For the short-term it considered availability of operating reserves, ancillary services (imports), and environmental constraints. The third indicator focused on the performance measurement of the transmission system. It considered for the long-term the expansion of the infrastructure, interconnections capacities, tariff system, and public acceptance of land uses. For the short-term it accounted congestion management procedures, network management, level of automation, and losses of the system. The fourth indicator was focused on the distribution system performance. The long-term took into consideration the expansion and reinforcement of the infrastructure, land uses and urban policies.

The short-term looked for the ageing of the facilities as well as to the network management. Their indicators also have included the evaluation of network operations, the capacities of the electricity transmission system infrastructure and operability (number of failures). This indicator evaluated the lines length and capacities, voltage, number of poles, number and type of substations, type, and conversion capacities. Finally, the study assessed the electricity market structure and performance in terms of stability, measure the participants' market power, and wholesale market performance.

The study of EURELECTRIC (2006) did not provide empirical data about the way to apply most of the proposed indicators and their components for measuring the performance of the electricity industry. However, most of them can be consulted in previous researches regarding energy security. The purpose of this is to reorganize and implement some of these indicators for measuring energy security in the electricity industry. The contribution of the study was to provide a well-defined vision about how the performance of an electricity industry can be evaluated, which by its own nature is closely related with the concept of energy security. Although it considered environmental constraints as a factor that can affect power generation for both short and long-term, it did not consider specific measurements to evaluate this variable.

The methodology developed by of Constantini et al. (2007) built long-term scenarios to assess energy security. The researchers aim was to evaluate dependence and vulnerability with the physical and economical scopes. The indicators defined for evaluating availability were conventional and unconventional reserves and resources. The utilized approach is based on prior scenarios created for analyzing the behavior of energy reserves and resources. The scenarios were put by the International Energy Agency (IEA), the International Institute for Applied Systems Analysis with World Energy Council (IIASA-WEC), the Intergovernmental Panel on Climate Change (IPCC), the US Energy Department (EIA-DOE), and the European Union with its World Energy Technology and Climate Policy Outlook (WETO). The methodology is composed by three steps. The results obtained showed the world's distribution of oil and gas also the undiscovered reserves for conventional and unconventional oil and gas resources.

For evaluating the level of dependency on oil and gas through the physical dimension, the net import as percentage of the total primary energy supply (TPES) was analyzed, and the share of a specific geographical area (Europe) for oil and gas imports of the world's oil and gas imports in percentage as well. For assessing the level of vulnerability from the supply side for oil and gas it was studied through the physical dimension of the degree of supply concentration for trade (IEA, 2007), the degree of supply concentration for production, and the Shannon-Weiner diversity index. In addition, the vulnerability for oil and gas from the demand side was also evaluated throughout measuring the share of oil used for transportation, the share of electricity produced with gas, and the supply of oil and gas consumed per capita.

Finally, for evaluating the level of dependency for oil and gas through the economic dimension, the supply of oil and gas imports was computed in monetary terms. The vulnerability of the supply side was assessed through taking into account the values of oil and the consumed gas divided into the gross domestic product (GDP). The factors that were considered and affecting energy security for a given country were the elements that integrate projected energy balances which were developed previously from governmental and regional agencies related to energy issues (IEA and IEA). The study is limited because the methodology does not take into account other factors affecting energy security such as environmental, political, and social issues. However, the methodology provides a general overview about how it can measure future situations affecting the macro-environment of the energy industry.

2.1.4 Diversity measurements

The research paper of Jansen, Arkel and Boots (2004) contained an empirical methodology based on the Shannon-Wiener diversity index, which was adjusted several times and in accordance to the requirements of their research. This formula composes the first and basic indicator, which allows evaluating the portfolios of primary energy resources. The second indicator intends to measure the degree of dependency and diversification of energy and electricity imports. The third indicator refers to political stability and they utilized the UNDP Human Development Indicator (HDI) for the case of the European countries. However, this indicator, which was developed by Mahbub-ul-Haq in 1990, is currently deprecated. The fourth indicator measures energetic resources depletion for the cases of biomass, nuclear, coal, gas, and oil. This final indicator is focused on measuring limited energetic resources. As it can be observed in this research an empirical approach has developed based on a cascade-type methodology, through adjusting the Shannon diversity index, for the creation and use of indicators that measure security of energy supply in the long-term for the European electricity markets.

Although the research was supported with and empirical approach the indicators developed it still limited for measuring all the potential threats that could affect security of energy supply in the electricity industry. The third indicator is the most limited since it only can be employed in countries that have already reached a certain degree of development and that hold stable political regimes. However, it also does not mean that it cannot be utilized, but surely it will require to be adjusted in accordance with the nature of less politically stable countries. The factors underpinning energy security are the energetic matrix composition, imports' behavior, political stability and measurement of limited energetic resources. For the researchers these are the factors which can influence in the long-run security of supply and price affordability.

For the IEA (2007) the starting point in measuring energy security is the influence of market concentration power over sub-sectors of the energy industry. It employed a formula based on the Herfindahl-Hirschman index. This procedure allowed in determining industrial organization patterns such as monopolistic or oligopolistic structures for each energy resource industry. The study continued with evaluating the political stability by multiplying the Herfindahl-Hirschman index with the risk evaluation for a determined country. Then the energy security price index is developed, which is the multiplication of the obtained results from the political stability of each type of combustible by the share of each in the country's energy matrix. Finally, the research developed the energy security index volume to determine imports of a specific energy resource divided by the country's total primary energy supply.

This final index contributed in estimating the degree of dependency in a specific energy resource and its implications in terms of energy security for the nation. As it can be seen, this research has developed an empirical approach based on a cascade-type methodology for the creation and use of indexes that measure energy security in terms of market concentration. This study and its model were developed to be utilized in a global environment over primary energy resources especially in fossil-fired fuels. The different indexes developed in this research provided measurements of the degree of energy security over primary fossil-fuels and a clear view of when it could be facing a situation of insecurity.

Although the relationship of primary energy resources with the electricity industry, the IEA (2007) research did not mention how to utilize these indicators in the electricity industry at the power generation level for example. For this institution the factors underpinning energy security of a country; are market concentration, political stability, energy matrix composition, economic effects, and imports of energetic resources. These factors have influence on ensuring uninterrupted supplies of energy resources that are vital for the production of electricity at an affordable price. However, Hughes (2009), Kruyt et al. 2009, lefèvre (2010), and Löschel, Moslener, and Rübbelke (2010) have criticized this model because it is too short to perform deeper analysis for the under study subject. In addition, these authors have conducted researches that have extended this conceptualization. They have added measurements based on a wide range of existing literature and classified them in accordance with the emergence of new needs to measure overall energy security of primary energy resources.

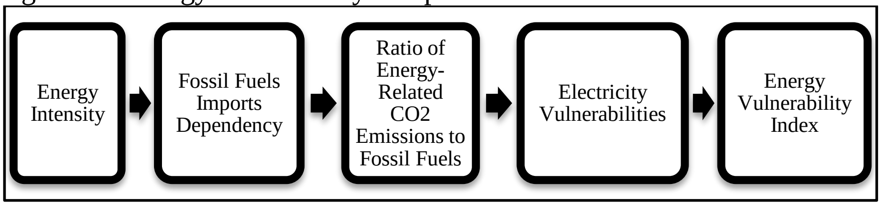
Table 2.2 Indexes for measuring diversity and concentration

Measurement	*Metric Formula*	*Acronyms' Meaning*
Simpson Index	$\lambda = \sum_{i=1}^{N} p_i^2$	p_i is the sample belonging to the population under study N is the population under study
Herfindahl–Hirschman Index	$H = \sum_{i=1}^{N} S_i^2$	S_i is the market share of firm in the market N is the number of firms
Shannon–Wiener Index	$H' = \sum_{i=1}^{N} p_i \log p_i$	P_i is the proportion of characters belonging to the i^{th} type issue of interest

Source: Skea (2010) and Stirling (1994)

Gnansounou (2008) employed an empirical methodology based on factors that can influence negatively the supplies of energy commodities. The main purpose of the researcher was evaluating energy vulnerabilities. The author has taken into account the ECN/CIEP criteria regarding factors that can affect the energy supply chain. The investigation was supported with several indicators from previous researches which allow identifying the threats regarding energy supply. The result was a composite indicator called energy vulnerability index, which allowed measuring weaknesses related to energy demand/supply. In terms of energy security this indicator is important because it focused on identifying threats affecting supplies of energy commodities, which decrease the certainty about having enough energy resources for producing fuels or electricity. The main factors decreasing security in this research were the resources intensities, imports dependency, pollutants emissions, and electricity vulnerabilities regarding imports behavior. Figure 2.1 illustrates the Gnansounou (2008) indicators for measuring energy vulnerability.

Figure 2.2 Energy vulnerability composite indicators



Source: Gnansounou (2008); Cabalu (2010)

This methodology also has encouraged other researchers (Cabalu, 2010), for adopting this approach and evaluates energy vulnerabilities in the electricity generation system in different geographical zones, which depends on gas imports for electricity production. All these studies provided a wide range of indicators clearly classified, which also granted developing criteria regarding the way to estimate insecurity of supply in the upstream market of the electricity industry. What may differ among them is the number of indicators or factors (energy vulnerabilities) regarded, because in the case of Gnansounou (2008 five issues) were accounted, while Cabalu (2010) took into account four matters. The research of Cabalu was the more accurate in comparison with the other two because the employed indicators were clear and precise, but limited just to assess the energy resources system. Table 2.3 present the general employed methodology.

Table 2.3 Energy vulnerability index

Measurement	*Metric Formula*
Energy Vulnerability Index	EVI = $[(\sum_{i=1}^{5} I^{2}_{ij})^{1/2}] \div I_{ij}$

Source: Gnansounou (2008); Cabalu (2010)

In addition, in terms of using relative indicators or scaled values Cabalu (2010) employed the maximums and minimums ranges values in order to perform better risks measurements. The scaled values can be considered as minimum standards that must be accomplished in order to obtain an acceptable performance. However, an extended analysis about situations and factors that might affect continuity of electricity supply in the other areas of the industry’s supply chain is still required. This model can be utilized in other areas that integrate the electricity industry’s supply chain. In addition, it is necessary to account the infrastructure capacities factors as well as the demand factors as the threats, which are the basic technical indicators in assessing security of supply for the electricity generation system.

The oil and gas import dependency indicator was defined as a function of oil and gas import ratio to TPES. It meant that net oil and gas imports of the country under study were divided by the TEPS. If the result obtained was positive the country was a net importer of both commodities. This indicator evaluated for both oil and gas the political stability through employing the Herfindahl-Hirschman index. It multiplied the square of the market shares of the supply origins by the risk estimation for a determined country or region, and then divided by the same risk estimation. The aggregate concentration factor was obtained by multiplying net oil imports by the political stability for oil. Then it was added to the result that was reached from multiplying net gas imports by the political stability for gas. Finally, the result was divided by the addition between net oil imports and net gas imports and then it contributed in establishing the oil and gas import dependency indicator.

The ratio of energy-related CO_2 emissions to TPES was obtained from dividing the country's CO_2 emissions into the TEPS. Its relative indicator was estimated by using the same scaling technique that was employed to obtain the first indicator of the study about energy intensity of the gross domestic product is measured by dividing the TPES between the GDP of the country under study. The non-diversity in transport fuels indicator accounted the different fuels that were employed in transport sector as well as the market share of each type of fuel. A logarithmic expression was employed in order to asses this indicator.

The electricity supply vulnerability indicator allowed measuring the net import of electricity. It was defined in terms of three dimensions. The net import of electricity was considered as being pre-eminent. For its calculation it was necessary to account the country's total capacity for imports of electricity, from which was subtracted the minimum amount of electricity imports during a specific period of time. Then, this result was divided by the subtraction of the maximum and minimum amounts of electricity imported during a specific period of time.

The second dimension was the concentration and non-public-acceptance of an eventual dominated technology of electricity generation. For this case, the author developed some assumptions in order to establish the public rejection for a specific technology for electricity generation, based on the share of electricity generation in the electricity supply and the share of the most used thermal technology for electricity generation. The third dimension was the non-diversification of that rejected generation. For its assessment the diversification index theory was employed. Finally, the energy vulnerability index was the composite index which was computed as the root mean square of the five relative indicators.

The aggregated indicators for assessing energy security were based on the Herfindahl-Hirschman and Shannon indexes, same as Jansen, Arkel and Boots (2004) and IEA (2007). It modified the original formulas in order to assess vulnerabilities of demand behavior, dependence on the supply of oil and gas fuels, pollutant emissions, electricity matrix, and non-diversity on transport fuels. It considered political stability for the supply side for primary energy resources, while for the electricity industry considered imports dependence, public rejection, and technological concentration. This study provided a wide range of indicators clearly classified, which also granted developing criteria regarding the way to estimate insecurity of supply in the electricity sector. However, in the case of electricity imports the research did not consider the impact over security of supply or high prices over the imports. The factors affecting security of energy supply were demand behavior in emerging economies, fossil fuels reserves, political challenges, the concentration of fossil fuels reserves, and social conflicts.

Kruyt et al. (2009) employed a qualitative-quantitative approach for measuring energy security. The scholars started by settling the four dimensions that energy security has to cover such as availability, accessibility, affordability, and acceptability. The first dimension hosts the factors regarding physical opportunities; while the second one accounts the elements concerning geopolitical issues. For its part affordability regards economic facts and acceptability to environment and social aspects. It can be noticed that this study intended to identify and classify the factors affecting the well-functioning of the energy industry at the business macro-environment. Later on these four dimensions were classified into a Cartesian framework and also were considered global orientations such as economic efficiency vs. environmental acceptability and globalization vs. regionalization. The developed schematic classification is the foundation for classifying the energy security measurements that were considered in the research. The measurements were organized into simple and aggregated indicators.

The simple indicators estimated comprehend resources, which account proved the existences of energy sources and it is the first hand direct indicators that can be obtained from the existence reports. The second simple indicator is composed by the reserves to produce ratios which try to provide criteria about the time of production left at current production levels. Later on it considered the diversity indices based on the Shannon index in order to measure the degree of supply concentration among geographical regions. The simple indicators also accounted import dependence, which is the result from combining the diversity index with the import dependence index. The diversity index is divided into the imports dependence index. Then it considered evaluating the political stability by employing the Herfindahl-Hirschman index which is multiplied with the risk estimation for a determined country.

The energy price has significant importance on measuring energy security with simple indicators according to the researchers. This factor provided information about supply and demand behavior, signals of scarcity, and economical implications. Mean variance portfolio is considered in order to assess energy matrixes. For this case the financial-economic theory can be utilized as support. The share of zero-carbon fuels is an indicator which considered the contribution of nuclear and renewable energies for reducing in one hand the dependency on fossil-fired fuels into the primary energy resources matrix, and in second hand reducing CO_2 emissions and strengthening environmental sustainability. Market liquidity accounts the positive balances between demand and supply of energy commodities. Finally, the demand-side indicators comprehend energy and fuel intensities for a given national economy. These indicators provide measures about how much dependent is an economy of energy resources.

The aggregated indicators for assessing energy security started through employing the Shannon index, which was a modification realized by Jansen (2004) at the original index in order to measure diversity issues for different type of fuels, suppliers, and imports. It also considered supply concentration and political stability for the supply side. The second indicator considered the two measurements accounted by the same as Jansen, Arkel and Boots (2004) and IEA (2007) for measuring energy security in its study of 2007. In both cases the measurements are based on the Herfindahl-Hirschman index. The supply demand (S/D) index is a measurement for the long term, which scores rule for assessing important issues related with satisfying demand requirements, supply, conversion and transportation of energy. This indicator considers all the technical issues related with the performance of the electricity industry. The principal components of this indicator are supply origins, efficiencies, reserve factors, network capacities, refinery and storage capacities. The outputs are shares.

The willingness to pay measurement, which is developed function in assistance of the prior realized studies by Gupta (2008) and Bollen (2008). This indicator measured the percentage of GDP that a country is able to pay in order to mitigate situations of energy insecurity. Among the elements that integrate the formula are high import quotes, high shares of oil and gas in total primary energy supply, and high intensities. Finally, the last aggregated indicator is the oil vulnerability index, which is also based on the study of Gupta (2008) and it takes into account the overall region-dependent scaling factor, time issues, regional concerns, import ratio of the fuel, the share of the fuel in the total primary energy supply, energy intensity in terms of consumption of energy per unit of GDP, and degrees of dependency.

This study compared with the research carried out by IEA (2007) provided a wide range of indicators which were clearly classified, also contributes in developing criteria about the way to asses energy security. However, the research is limited for the social and environmental contexts as it can be seen in figure number two. Natural phenomena affecting energy security is not considered into this research. The reason is because they do not develop novel indicators. The research was based on prior studies and indicators. The authors just classified properly the measurements for assessing energy security. However, despite that the research is well organized, clearly identifies the measurements, and provides criteria for energy security actions; it is limited to evaluate with an econometrical model the impacts of these variables over energy security issues.

Table 2.4 Imports dependency measurement

Measurement	*Metric Formula*	*Acronyms' Meaning*
Net Energy Import Dependency (NEID)	NEID = $\sum_i m_i p_i \ln p_i \div \sum_i p_i \ln p_i$	m*i* is the share in the net imports of energy carrier *i* p*i* is the share in total primary energy supply (TPES)

Source: Kruyt et al. (2009)

Lefèvre. (2010) developed a qualitative-quantitative approach for measuring energy security. The researcher started by defining the causal relationships of anthropogenic climate change, which are product of human activities. In the case of price its behavior is a product of fossil fuels resource and supply concentration. The physical availability is subject to fix contract mechanisms as well as the rigidity of the infrastructure. The scholar considered the quantitative approach for measuring the price and the physical availability implications of fossil fuel resource concentration in competitive markets as well as to the implications of political stability. The employed methodology was based on the Jansen, Arkel and Boots (2004) and the IEA (2007) approach, and it intended to assess energy security market concentration through the employment of the Herfindahl-Hirschman index. The squared market shares for all the participants in a competitive market was required and then added together in order to obtain the index. The case studies were France and the United Kingdom.

Fossil fuel resources around the world are placed and concentrated in geographical areas with sensitive political regimes and therefore it is required to account the political stability for energy security market concentration. This indicator was a slight modification of the Herfindahl-Hirschman index. The market share was assumed to be composed by several countries with an individual squared share which was multiplied by each nation political risk in order to obtain the indicator, and then the energy security price index was employed. The methodology for obtaining this indicator suggested estimating, first the value of energy security market concentration and political stability for each type of fossil fuel. The obtained result was multiplied by the value that was obtained from dividing the country's supply that was exposed to price risks for a specific fuel and its total primary energy supply. Finally, the researcher used the energy security physical availability index. And as a result, it was the supply of gas that was imported by pipeline based on regulated contracts and it was divided by the total primary energy supply.

This study was an application of the considered indicators previously by Jansen, Arkel and Boots (2004) and IEA (2007). The study was well organized and it provided a clear example how to asses energy security. However, the research was limited for environmental phenomena although the researcher considered that at the beginning of his study. Regarding the empirical approach we can assume that Herfindahl-Hirschman index was a popular tool that not only measured levels of concentration but also for determining the presence of monopolies.

Although it was a commonly accepted method, still there were many problems with its results. For example it cannot be useful in markets with natural monopolies such as electricity transmission and distribution. However, it can be useful in deregulated electricity markets at power generation level with a wide range of participants.

Löschel, Moslener and Rübbelke (2010) developed a quantitative approach for measuring energy security. The researchers started through utilize the Jansen, Arkel and Boots (2004), the IEA (2007), and Kruyt et al. (2009) indicators for measuring energy security. Then it considered the dimensional scope in measuring energy security. The scholars defined ex-post and ex-ante indicators. The ex-post indicators intended to determine when the energy industry produces conflicts with the economy, while the ex-ante indicators intended to identify risks affecting the economy in a future panorama. The ex-post indicators had two main components based on prices and volumes. The volumes were a synonymous of availability. The prices and volumes considered historical and present values of energy commodities. In the case of volumes they considered supply capacities, reserve capacities, and unused national extraction capacities.

The energy security price indicator was composed by current prices of the energetic commodities. This value was divided by the mean value of historical prices of the energetic commodities in the mid-term. If the past prices were higher than the current ones, it meant that currently a situation of energy insecurity had been solved. In the other hand, if the current prices were higher than the past ones, it meant that a situation of energy insecurity had started to happen. The energy security volume indicator was produced by current supply capacity, which was the value of present supply capacities, present reserve capacities and unused national extraction capacities. Then, it was divided by the past mean value of supply levels. If the past volumes were higher than the current ones, it meant that a situation of energy insecurity can occur in the future through alter prices because of reducing levels of energetic feedstocks. If the present volumes were higher than the ones in the past, it would probably signify that new reserves had been discovered and added, and that an energy insecurity situation was far to happen.

Finally, the researchers developed an ex-ante indicator with the support of existence literature by doing a minor modification on the IEA s energy security market concentration indicator for political stability. They employed the same formula considered by IEA but in a scenario that did not include the political risks and in which it was considered as in the original. The scholars recommended employing with this indicator another type of energy commodities such as biomass; however, they did not utilize it in their study. This study was an application of the indicators reflected previously by the IEA (2007). The study was well organized and it provided a clear example on how to asses energy security in a dimensional area. However, the research was limited in considering other factors that may affect energy security. Their methodology can be useful in assessing prices and volumes in order to assess energy security in the electricity industry.

Table 2.5 IEA s Energy security indicators

Measurement	*Metric Formula*	*Acronyms' Meaning*
Energy Security Market Concentration (ESMC)	$\text{ESMC} = \sum_i S_{if}^{\ 2}$	S_{if} is the share of each supplier *i* in the market of fuel *f* defined by its net export potential
Energy Security Market Concentration for Political Stability (ESMC_{PL})	$\text{ESMC}_{\text{PL}} = \sum_i (r_i \cdot Sif^2)$	*r* is the political risk rating of country *i*
Energy Security Index Price ($\text{ESI}_{\text{Price}}$)	$\text{ESI}_{\text{Price}} = \sum_f [ESMC_{PL\text{-}f} \cdot C_f \div TPES]$	$C_f \div TEPS$ is the share of the fuel mix $ESMC_{PL\text{-}f}$ is the energy security market concentration of the international market for fuel *f*
An Energy Security Index Volume ($\text{ESI}_{\text{Volume}}$)	$\text{ESI}_{\text{Volume}} = \chi_i \div TEPS$	χ is the net imports of fuel i *TEPS* is the total energy primary sources

Source: IEA (2007)

Hippel, Savage and Hayes (2011) developed a qualitative-quantitative approach which employed a tool called long-range energy alternatives planning for assessing energy security. Then the dimensional scope on measuring energy security was considered. The main components that this tool employed for evaluating energy security were costs of energetic commodities, physical energy output, fuels imports and exports, and environmental emissions. The empirical methodology considered the use of the diversification indices, which were based on the Herfindahl index as the case of IEA (2007), Kruyt et al. 2009, Lefèvre (2010), and Löschel, Moslener, and Rübbelke (2010). On the other hand, the qualitative approach employed a multiple-attribute analysis and matrices. It was contributed in order to develop frameworks for assessing policies and performances. The matrices can show results in terms of costs of energy commodities, impacts over environment in terms of pollutants emissions, policies utilized on energy mixes, energy demand and supply, and achievement of plans.

Energy security in their study covered six dimensions. It started with energy supply, which considered total primary energy, fraction of primary energy as imports, and diversification index. The economic scope considered total energy system internal costs, import fuel costs, economic impact of fuel price increase as fractions of the gross national product (GNP). The technological arena accounted diversification indices for key industries by technology type, diversity of R&D spending, reliance on proven technologies, and technological acceptability. The environmental concerns focused on measuring pollutant emissions, ecosystem and aesthetic impacts, and the exposure of environmental risk. The social and cultural dimension took into account the exposure of risk on social or cultural conflict over energy systems. Finally, the military/security arena, which considered the exposure to military/security risks and the relative level of spending on energy related security arrangements.

They employed a methodology which considered several dimensions for energy security. However, the methodology was limited since it mostly based on a qualitative approach rather than a quantitative analysis which allowed extending the criteria about the issues affecting energy security. In the case of the environmental as well as the social and culture issues it was not clear how to measure them. The study did not say in specific which sub-sector of the energy industry they were assessing.

The research of Cohen, Joutz and Loungani (2011) intended to measure the influence of diversification of suppliers for energy resources. The methodology was based on the Herfindahl-Hirschman index, which allowed measuring the degree of diversification for each energy resource in terms of countries of origin. The original formula was transformed into two subsequent diversification indexes. The first subsequent index intended to measure the share in terms of total production for each country. The second one tried to measure the share in terms of net exports for each country. The study continued with evaluating the political stability with the support of the Herfindahl-Hirschman index which was multiplied by the risk evaluation for a determined country. As it can be seen this research has developed an empirical approach based on a cascade-type methodology for the creation and use of indexes that measure energy security in terms of market concentration.

This study was developed in order to measure the security of energy supply through examining the degree of dependency in importing primary energy resources from specific countries or markets. In addition it allows identifying when a country is shifting from a small to a large number of suppliers of energetic resources. The different indexes developed in this research provide indicators which allow assessing the market power that specific global suppliers can exercise over primary fossil-fuels. Also, it provides a clear view of when a country could be facing a situation of insecurity due to its high levels of dependency. The factors underpinning energy security of a country are market concentration, political stability, energy matrix composition, and imports of energetic resources. This study is quite similar to the ones developed by Jansen, Arkel and Boots (2004), the IEA (2007), and Kruyt et al. (2009). The difference is the fact that the indicators developed consider specific characteristics of the countries under study.

2.2 Energy security in terms of accessibility

2.2.1 Generation infrastructure efficiency

Data envelopment analysis (DEA) was utilized by Golany, Roll and Rybak (1994) for assessing efficiency of power plants. The methodology was based on linear programming through considering each power plant a number of generating units as well as its installed power capacity in terms of megawatts (MW). The aim was to measure the efficiency of multiple decision-making units as the case of generation power plants which presented a structure of multiple inputs and outputs. This nonparametric method contributed in estimating production frontiers. The researchers employed a regression analysis in which the dependent variable was generated power. The independent variables for the outputs side were operational availability, deviation from load, deviation from operational parameters, and sulfur dioxide (SO_2) emissions. Pollution emissions were considered as a qualitative factor. In the other hand, for the inputs side the independent variables were installed capacity, fuel consumption, internal power, capital, manpower, miscellaneous expenses, and fuel stocks. Special attention must be placed the most relevant input and output factors.

$$\textbf{\textit{F.1}}\ Y_i = \beta_1 X_{i1} + \ldots + \beta_p X_{ip} + \mathcal{E}_i$$

$$\textbf{\textit{F.2}}\ \sigma_p = \sqrt{(}\chi_i^2\sigma_1^2 + \chi_2^2\sigma_2^2 + 2\chi_1\chi_2\rho_{12}\sigma_1\sigma_2)$$

It can be seen that this function showed the general model employed in the regression, where Y_i was the dependent variable, β is a ρ-dimensional parameter vector, X_i were the independent variables, and ε_i was the error term. Capacities also were simple indicators, which account proved installed power capacities and it was the first hand direct indicator that can be obtained from existence reports. DEA approach can be employed also for assessing the performance and efficiency of power grids at electricity transmission and distribution levels. Furthermore, the technological progresses reached currently allowed monitoring real time voltage traffic and capacities over power grids in order to avoid overvoltage collapses (Harrison and Wallace 2005; Cooper, Seiford and Zhu 2011).

Paulus, Grave and Lindenberger (2011) developed an investigation based on a qualitative-descriptive analysis for measuring the performance of the electricity industry at power generation level as the case of Gosh (2010). Their methodology was based on the indicators contained in the so-called generation capacity balances. The information contained in the so-called generation capacity balances was used to develop the notion of secured capacity and later on employed into a stochastic probabilistic model to obtain probabilistic distribution functions and as well as probabilistic density functions. The model was useful for modeling different type of energy resources and technologies.

The statistical results that were obtained from the so-called generation capacity balances were employed in the computer-based dispatch and investment model for electricity markets in Europe (DIME) in order to develop long-term projections. The estimate was computed by weighting each power plant project under study with regard to its realization probability. Results of the linear optimization model serve as investment decision scenarios as well as optimized dispatch scenarios for spot and reserve markets. Finally, their results suggested that electricity supply at power generation level can be ensured if the installed capacities and energy resources were enough for covering electricity peak demand for a specific period of time.

Among the findings that the researchers found was the fact that it was possible to determine statistically the amount of the available power generation capacities, which provided security of supply. The study was limited in terms of the number of indicators as well as showing how the methodology can be developed step by step. The required formulas supporting the investigation were not included too. However, this analysis was a useful tool for policy makers and investors in order to determine the proper moment for increasing the installed capacity and strengthen the security of supply.

In this research among the factors that were considered were the electricity matrix, energy resources, demand, and cost per kilowatt hour. The descriptive methodology employed by the researchers allowed assessing security of electricity supply from intermittent energy resources. The scholars said that so-called generation capacity balances did not vary over the time due to its static nature. However, we do not agree with that statement since capacities can differ between installed and effective, especially for technologies based on renewable energy resources, which are intermittent. The study was limited by the fact that it was required to make a deep analysis of situations and factors that can alter prices and availability of electricity.

Zhenzhen and Jirutitijaroen (2011) developed a quantitative research for assessing energy vulnerabilities that can affect the performance of the electricity industry negatively, specifically at power generation level. Minimization techniques were utilized as well as the evaluation of several indicators. The research explained several equations in order to set the basic parameters for establishing optimal generation mix because of cost minimization where it was based on previous study of Gnansounou (2008). We found several factors employed in assessing security of supply. We classified them by costing, infrastructure characteristics, and general technical measurements. Among the costing components were construction costs defined by the power plant capacity and the type of the used fuel, fixed and variable operation and maintenance costs, carbon emission price, and fuels' prices. Regarding infrastructure characteristics, we found generation installed capacity by type of power plant, fuel types, electricity generated from existing power plants, electricity generated from new power plants, and available capacities by type of fuel. The general technical measurements took into account electricity demand, time periods, carbon emission rates by type of fuel, conversion index by type of fuel, and energy resource inventories.

The study also developed a security index model based on prior research of Cabalu (2010). It assessed gas intensity, net gas import dependency, ratio of domestic gas production to total domestic gas, and geopolitical risks. The first indicator evaluated the intensity in the use of natural gas through measuring the total of natural gas consumption in a specific country divided by its gross domestic product. The second indicator aimed to assess the net gas import dependency in order to account the net imports of natural gas in a specific country divided by its total primary energy consumption in that nation. The third indicator evaluated the ratio of domestic gas production to total domestic gas. In this case the total production of natural gas was accounted if the country was the net producer, and it was divided into the nation's total consumption of natural gas. Finally, it assessed the geopolitical risk through employing the Shannon diversity index, which was adjusted for political stability in exporting countries. This final indicator considered the political stability for a specific country, the share of gas imports from a determined country in total gas imports.

All the indicators had a dimensional scope since they allowed comparing with other countries in terms of energy security. It can be considered as an extra of the research since it was something that should not be necessary at power generation level because the main purpose was assessing the continuity of energy supply and solve problems if they existed. In addition, all of them were squared and added, then divided by four, in order to obtain its square root and get the security index for gas. This study showed how to asses energy supply in the electricity industry, but based on gas facilities for the production of electricity.

The study was limited since it did not consider the effective capacities for power facilities, which was a basic technical indicator in assessing security of supply as well as importing prices compared with domestic prices. The model developed by the researchers intended to understand the dynamics of the electricity markets at the power generation level. It was required an extended analysis about situations and factors that can affect security of electricity supply. This study seems simple as the one accomplished by Hughes (2009) and Winzer (2012).

2.2.2 Electricity industry performance

Jamasb, Newbery and Pollitt (2004) employed a qualitative analysis of previous theories regarding indicators for measuring the electricity industry performance. They developed a set of core indicators for analyzing the electricity sector output. The researchers developed nine different indicators and sub-indicators in order to measure the electricity industry's behavior. It used a matrix table for each of the nine indicators and sub-indicators were established based on specific areas. The referred investigation as much as it was possible the data references from where the indicators were obtained. The first indicator is encouraging to evaluate the industry endowments and characteristics. This indicator in terms of energy security considered the electricity generation mix, supply and demand behavior, resource availability and level of dependency, electricity service costs, and proven potential in other energetic resources (Fanchi 2000). Also, the supply and demand behavior related to electricity consumption, domestic production, imports, and exports for determining if a country is self-sufficient on supplying this commodity for its inhabitants.

The second indicator focused on identifying the nature of the electricity sector. In other words, it referred if the electricity industry whether public or private was regarding regulation or deregulation issues (Zhang et al. 2002). The aim of the third indicator was providing a guide in the case of policy makers for evaluating the industrial organization model through measuring market power concentration and to establish the positive or negative effects over the industry's performance. The fourth indicator wanted to evaluate the industry's regulation, organization and way to be governed. The fifth indicator took into account most of the technical issues including type of investments. Among its components were installed capacities efficiencies, losses on the different systems, infrastructure efficiencies, and reserve margins. The sixth indicator proposed an indicator which elements intended to measure firm's performance in terms of infrastructure capacity, number of customers, number of minutes without the service, number of interruptions in a year, operational and maintenance costs. The last indicators took into account macro level components such as economic, social, and environmental.

Among the economic sub indicators energy intensity, country risk, GDP per capita, the electricity industry output within the GDP, and electricity consumption per capita were found. The social impacts took into account consumer prices, economic welfare, and access to the service, energy use, and continuity of the service. Finally, the environmental concerns were focused on CO_2 emission reductions (Sun, 2003; Ürge-Vorsatz and Novikova, 2008; Timilsina, 2008; Pao and Tsai, 2010; Duan, 2010). As it can be comprehended this study covers a wide range of areas and developed a set of indicators in order to determine the performance of the electricity industry. Some components of the main indicators were repeated again inside of other indicators. Most of these indicators provided acceptable criteria on measuring energy security although it is not the main purpose of the study, but keeping the relationship between performance and the concept of energy security they can be utilized in a more structured classification.

The study of Jamasb, Newbery and Pollitt (2004) did not provide extended empirical information about the way to apply most of the proposed indicators and their components for measuring the performance of the electricity industry. However, most of them can be consulted in text books (Laughton and Warne, 2003; Casazza and Delea, 2010; Bird, 2012). The purpose of this is to reorganize and implement some of these indicators for measuring energy security in the electricity industry. The contribution of these researchers is to provide a broad vision about how the performance of an electricity industry can be evaluated, which by its own nature is closely related with the concept of energy security.

Table 2.6 Measuring electricity generation mix and prices

Measurement	*Metric Formula*	*Acronyms' Meaning*
Electricity Generation Mix (EGM)	EGM = $\chi_i \div$ TEPR	χ is the amount of resource known *i* is a specific energetic resource TEPR is the total amount of primary energy resources
Electricity Service Price (ESP)	ESP = P_q	*P* is a monetary unit expressed in dollars of the United States of America (US \$) *q* is the amount of kilowatt hour (KWh) served at the final customers

Source: Laughton and Warne (2003); Casazza and Delea (2010); Bird (2012)

Pérez (2007) employed a qualitative approach, which integrated the existent indicators for measuring the outcomes produced by the electricity industry. It is based on previous researches developed by specialized institutions related with the electricity sector. The investigation integrated the different concepts that already existed into two main categories. The first category was composed by four dimensions and it was initiated with the concept of security, which must be the certainty in the provision of the electricity service in the short time. It can be measured as an output of the system operator performance.

We understand by system the different areas which integrate the electricity industry such as generation, transmission and distribution. It established that firmness was the available infrastructure which guaranteed the supply of the service for the short and mid-term. That can be evaluated through analyzing the cost theory related within the systems operation and maintenance (Zhenzhen and Jirutitijaroen, 2011; Rodilla and Batlle, 2012). The third dimension was adequacy which was a long-term indicator due to the performance of the installed capacities in the different electrical systems. Finally, the four dimensions accounted strategic energy policy for which energy matrix diversification was the main factor and it was a long-term measure.

The second category referred to the principal activities related with the electricity industry. It started with the System Operator which was in charge to guarantee the perfect functioning of the system at the wholesale level. Then it considered the different electrical systems and for each system took into account operation and maintenance status and costs. Also, it considered the physical infrastructure that was available. This research was not supported by empirical models. We concluded that the investigation is very general and it is limited for understanding in detail how to measure security of electricity supply. The factors around security of supply are generation matrix composition, installed capacities in the different systems of the electricity industry, and pricing.

The Regional Centre for Energy Policy Research (REKK; 2009) developed a research paper based on a qualitative-quantitative analysis for measuring the performance of the electricity industry. Existent indicators were classified in accordance with the short, medium and long-term. For the short-term the indicators were based on the service quality. This indicator included voltage quality, continuity of supply for transmission and distribution systems, and commercial quality. The continuity of the supply was measured through the system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI), customer average interruption duration index (CAIDI), and the amount of not supplied energy (ENS). These indicators were widely explained by IEEE (2002) and Yeddanapudi (2005).

These indicators clearly set the way to be measured. For the medium-term it had taken into account two main indicators. The first one was based on the standards of the Union for the Co-ordination of Transmission of Electricity (UCTE). The standards were power balance, time horizons, reference points, load, load management, generation forecast scenarios, net generation capacity, unavailable capacity, reliable available capacity, remaining capacity, exchanges, margin against peak load, remaining margin, spare capacity, adequacy reference margin, and simultaneous interconnection transmission capacities (Duncan and Sarma, 2003). The second one was the REEK index, which was an expansion of the UCTE standards. The indicator considered the availability capacity of different technologies. For the long-term indicators the study was considered to measure diversity of technologies and energetic resources through the Shannon-Wiener index.

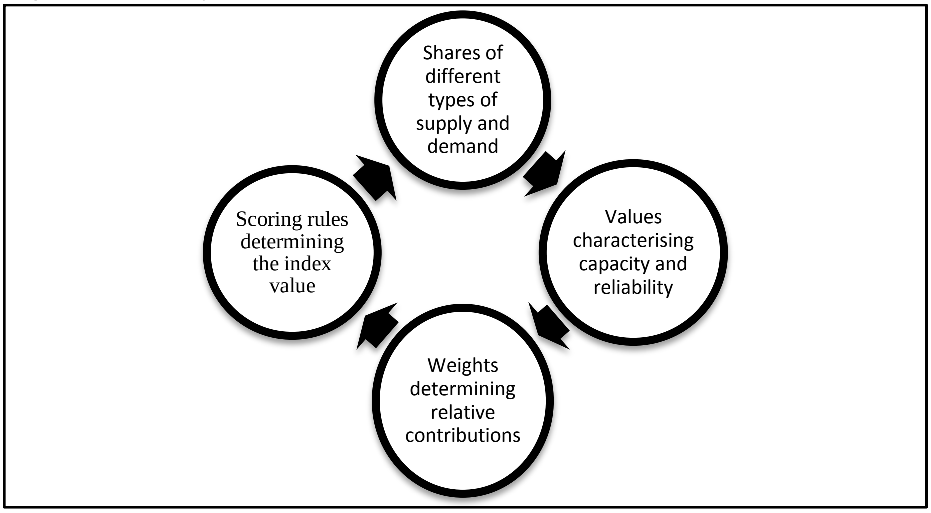
This study compared with the research carried out by EURELECTRIC (2006) provided an empirical data regarding the way to apply most of the proposed indicators and their components for measuring the performance of the electricity industry. In both cases the developed indicators provided an accurate overview for measuring energy security in the electricity industry. Although the research of REKK (2009) was well organized it did not consider negative environmental impacts that can affect power generation and reduce security of electricity supply.

The research paper of Qureshi and Sonnsjö (2011) developed an empirical methodology based on existent literature regarding measurements of energy security. The method began with the introduction of the oil-vulnerability index, which was conceived by Gupta (2008). This indicator accounted risks such as market (economic), supply and environment. The second indicator intended to measure the willingness to pay insecurity situations (Damigos, Tourkolias and Diakoulaki, 2009). The indicator was based on the prior methodology developed by Bollen, Hers, van der Zwaan (2010), and it is a penalty function of expressing willingness to pay. Among its components we found the overall region-dependent scaling factor, time issues, regional concerns, import ratio of the fuel, the share of the fuel in the total primary energy supply, energy intensity in terms of consumption of energy per unit of GDP, and degrees of dependency. The third indicator for measuring energy security was a decision matrix, which allowed evaluating different fuels alternatives. The matrix was based on the prior research accomplished by Hughes and Shupe (2011).

The fourth indicator was the diversity index, which was a notion developed by Shannon (1948). The indicator measured the energy resources that compose an energy matrix. The fifth indicator was based on the standards of the Energy Research Centre of the Netherlands (ECN) developed by Scheepers et al. (2007). This indicator was composed by three sub-indicators. The crisis capability index was a combination of the country risk and sudden supply interruptions. The supply/demand index accounted shares of different types of supply and demand, and capacity values, scores and weights. The supply of security index is a combination of the crisis capability index and the supply demand (S/D) index, and it intended to measure security of supply crisis. These last two indicators were previously referred by Scheepers et al. (2007).

The research was supported with an empirical approach through the mentioned indicators. The indicators revised were mostly for measuring situations of insecurity of energy supply at primary energy resources level. However, the researcher in his conclusions had shown that there were threats that had not been addressed in the literature regarding energy security. The risks threatening security of energy supply can be identified in the scheme developed by Kruyt et al. (2009) regarding acceptability, accessibility and availability. The author's conclusion was based on identifying which areas were more concentrated the existent indicators in the literature regarding energy security. For its side Hippel, Savage and Hayes (2011) had judged this model and had tried to extend the concept of energy security through adjusting prior measurements in accordance with their points of view.

Figure 2.3 Supply demand index model



Source: Scheepers et al. (2007)

2.2.3 Technical issues

Regarding electricity service availability Sumper et al. (2005) employed an empirical methodology based on previous technical indicators for assessing continuity of supply on the electricity industry. The researchers used three indicators which were considered as the main ones in assessing the electricity industry performance as a whole system. These indicators are the system average interruption frequency index (SAIFI); the system average interruption duration index (SAIDI); and the customer average interruption duration index (CAIDI). Winzer (2012) supported the authors' ideology in order to consider that these indicators were fundamental on assessing energy security in the electricity industry. However, both researches were limited since they did not consider more indicators for monitoring and evaluating the industry's performance in a complete technical way and in the case of the second researcher the study did not include the required metric formulas.

Analyzing the thesis of Yeddanapudi (2005) and the research paper of Rangel et al. (2010) we found a more detailed set of indicators for evaluating technically the performance of the industry. The indicators can be organized in three different areas. The first component focused on assessing situations of insecurity of electricity supply which has direct relationship with availability. It composed of the electricity not supplied (ENS); the customer total average interruption duration index (CTAIDI); the customer average interruption frequency index (CAIFI); the average service interruption frequency index (ASIFI); the momentary average interruption frequency index (MAIFI); and the average service interruption duration index (ASIDI).

In the other hand, the second area was oriented in assessing situations of availability such as the country's total installed capacity generation system (TIC_{GS}); net capacity factor (NCF); the average behavior of the frequency in the national interconnected system (ABFNIS); electricity produced (EP); electricity consumed (EC); electricity exported (EE); electricity imported (EI); inventory levels for energetic feedstocks (ILEF); and the average service availability index (ASAI). Finally, the third component focused on assessing economic impacts of interruptions on supplying the electricity service such as the costs of electricity not supplied (CENS).

Augustis et al. (2012) based their investigation on an empirical approach for energy security level assessment technology. The researchers developed an energy security level assessment algorithm. The factors under study were energy system, the generators, power distribution and power supply networks, storages, suppliers, and consumers. In other words, it considered them as factors influencing energy security and the different type of technologies as well as employed energy resources for producing electricity. Also, technical issues influencing electrical infrastructure, in addition to supply and demand behavior. The study mentioned the risks affecting energy security such as technology, environment, sociopolitical and economic issues, as well as terrorism and conflicts.

The main indicators of this research were average ratio of power units' lifetime with their technical resource time, the ratio of total gas pipeline capacity to maximum gas consumption, the ratio of the capacity of used nuclear fuel repository to demand, the ratio of the amount of electricity purchased in the electricity market to average annual demand for electricity, the portion of consumers that freely selected the electricity producer and the ratio of the 1000 cm^3 of gas purchase cost to EU countries average gas purchase cots. Similar factors were considered by Kennedy (2007), Watson and Scott (2009), and Corner et al. (2011) in a study related with nuclear energy and energy security. Also, the possibility for consumers to choose a gas supplier, the share of imported gas from the single possible supplier, the degree of undertaking the commitment with regard to renewable energy sources in the total final consumption, the degree of following the requirements of Kyoto Protocol regarding the reduction of greenhouse gas emission and the degree of undertaking the commitment regarding energy saving. Finally, the positive societal assessment concerning the development of nuclear power in the country was measured.

The study explained from where the data was obtained in order to asses each indicator. However, it did not say how to asses each indicator, only these results were employed into their energy security level assessment algorithm. This research was limited because it did not provide more explanations about the employed indicators, specifically about how they assessed security of supply regarding their relationship with energy. This study was limited by the fact that it was required to make a deep analysis of other situations and factors that can alter prices and availability of electricity as well as presenting impacts over the economy.

Table 2.7 Energy security level assessment technology

Measurement	*Metric Formula*	*Acronyms' Meaning*
Energy security level assessment algorithm	$B = \sum_{i=1}^{n}(S_i\sum_{j=1}^{m}(S_ij\sum_{k=1}^{l}S_{ijk}\chi_{ijk}))$	X_{ijk} indicators; *n* indicator block number *m* group number in the block; *l* indicator number in the group, and *i* =1, *j* = 1, *k* = 1

Source: Augustis et al. (2012)

2.3 Energy security in terms of affordability

2.3.1 Industrial organization

Creti and Fabra (2007) employed an empirical approach based on the microeconomics theory for analyzing the industry's organization as the case of de Vries and Heijnen (2008.) The methodology allowed evaluating the so-called installed capacity markets. The microeconomics theory was employed for analyzing monopolistic model as well as perfect competition. The results suggested that firm’s short-run opportunity costs were based on incentives for providing capacity reserves into the system. However, the study was limited since it did not consider the long-run effect over investment and just assumed that more regulations were required to be addressed in order to stimulate investments for adding more installed capacities.

The main factors which influence security of supply were installed capacities, domestic and foreign market prices, rate of utilization of the systems, demand and supply behavior, costs, electricity generated, incentives mechanisms, electricity imports and exports, and the number of firms at the generation level. This study was limited by the fact that it was needed to make a deep analysis of other situations and factors that can alter prices and availability of electricity as well as present impacts over the economy. For measuring security of supply more indicators should be considered. Brunekreeft (2002) considered similar factors.

Schwenen (2011) made a dissertation which was conducted through the development of a set of research papers which allowed the researcher to utilize the microeconomics theory for the development of his own models and support his investigation. The first research paper regarded market design and supply security in imperfect power markets. The author focused on developing a model for analyzing energy-only market and capacity market design. The first type of market structure was common in some European countries, while the second one was distinctive in the US electricity markets. For both cases this empirical research developed several equations in order to set the basic parameters for establishing market prices.

Among its components were the demand behavior, supply participants (duopolistic structure), biding prices, firms' installed capacities, and market total available capacity (Nooij, Koopmans, and Bijvoet, 2007). The equations developed a supporter for the application of microeconomics theory to find market equilibrium and probable electricity outages which decrease security of supply. Between the author's findings was the fact that firm's behavior under duopolistic market structure and with similar capacities can increase insecurity of electricity supply. Large firms can contribute by reducing electricity outages. However, the market design will depend on both factors firm's size and regulations that can affect security of supply positively or negatively.

The second research paper was about the benefits that can be obtained in real-time pricing within the electricity markets, particularly at power generation level and it is and indicator that was also considered for Kirschen (2003) for assessing power system security. There are two firms competing under a duopolistic market model and with similar price auction. The firms behaved under Cournot duopoly model. The research considered consumers' real-time demand with and without smart metering. In both cases the empirical model was developed in order to establish market equilibriums, quantify demands, prices, profits, and surpluses. The model was supported by a wide range of equations which were developed under the basis of microeconomics theory. The parameters under consideration were price, demand, number of firms and its characteristics, and operation and maintenance costs.

For pricing effects, the model took into consideration commercial operations which take place in both the wholesale electricity market and retailer market. The author found that market power due to firm's size can influence insecurity of electricity supply and price affordability. Also, that welfare depended on factors such as demand's behavior and level of firm's installed power capacities. The third research paper intended to identify biding behavior on the capacity market. In this case the market under study was the New York Capacity Market. One of the characteristics of this model was the fact that there were several firms at the power generation level.

The researcher considered firms' biddings through measuring its size in terms of market power and installed capacity. The firms behaved under Stackelberg model. The research considered the supply capacities and the consumers' demand, which were provided by the electricity wholesale market. The empirical model was developed in order to establish market prices and profits. Also, the model was tested through input data and with the aim to identify capacity constraints and market power influence. The model was supported by a wide range of equations which were developed under the basis of microeconomics theory.

The parameters under consideration were price, demand, number of firms and size in terms of market share and capacities like IEA (2007). In addition, a linear regression was developed in order to test bidding behavior. The criterion under consideration was the market follower firms' bids against the market leader bid. The author found that market leader firm had influence over the settled prices for trading electricity. The market leader firm was based on its market share and installed power capacity. Although, the leader firm offered most of its capacity it was not enough to ensure security of electricity supply. The wholesale electricity market required to incentive the follower firms through reward their capacities, a fact that at the end of the day increased the price of electricity and induced energy insecurity and affected economic.

This study focused on the security of supply in electricity markets. The econometric models developed by the author intended to understand the dynamics of the different electricity markets. Microeconomics theory was fundamental in supporting the joint researches, especially the one regarding market models and game theory. In the beginning of the dissertation the researcher mentioned the instability of electrical infrastructure based on renewable energy resources and their influence on securing electricity supply. However, as the investigation unfolded, it can be established that both the theory and used econometric models did not support such argument in a sustained way, perhaps by the nature of the study itself. However, it is likely that this argument had been made based on the behavior of different installed capacities that were considered during the accomplished researches.

2.3.2 Cost-efficiency

Nooij, Koopmans and Bijvoet (2007) developed a descriptive research for assessing the costs of power interruptions. They consulted surveys/interviews which contained data about people perception about damages in case of electricity service outages. The obtained results were reflected in the satisfaction by the households’ side due to the interruption of the activities that they were attending at the moment of the interruption. The production-function approach allowed determining impacts over productive sectors. Productivity was possible to measure when interruptions in the electricity service supply happened in business entities. In addition, through surveys information about the existence of contracts as well as the mechanism were obtained in order to avoid electricity shortage by both households and business entities. It allowed determining how much security of electricity supply was valued as well as the willingness to pay for safeguard the service provision. Case studies also were consulted in order to understand real experiences instead of hypothetical situations. In the case of households, the researchers measured the costs of power interruptions through consider the wages average costs in the country under study (Jadán 2009).

Since electricity depended on activities that were undertaken by households as well as productive entities, the scholars considered a situation in which one household stops to do an activity during one hour. It supposed that the activity produced satisfaction for the customer and the only way that it can be measured was through giving it a cost value. The costs of power interruptions can be considered as an opportunity cost. The way that the authors decided to allocate a cost for power interruptions was through giving it a value. This value was represented as the average wage of working one by the customer side. The referential value was consulted in the national statistics agency in the country under study; projections were developed in order to accomplish the research, and presenting results and implications for the different sector on the national economy.

In this research among the factors that were considered were electricity demand, cost per kilowatt hour, households and firms activities, average wage by type of social stratum, time, as well as firms' production costs and benefits. Analogous factors were considered by Saha and Moody (2003) as well as LaCommare and Eto (2004) in their researches. The descriptive methodology employed by the researchers allowed assessing the costs of power interruptions for different sectors of an economy. However, the study was limited by the fact that after gaining the losses of welfare for each sector, including households, it was not related with the impact that it had within the gross domestic product. Therefore, it was necessary in order to support the importance of the electricity industry and its direct relationship with a national economy and for the foregoing reasons the necessity to guarantee the electricity service supply.

Roques, Newbery and Nuttal (2008) employed an empirical approach in order to assess the cost-efficiency of different energy projects for producing electricity. The researchers used mean-variance portfolio theory approach. The obtained results reflect the optimal electricity matrix for securing electricity supply. The mean-variance portfolio theory was based on Markowitz (1953) seminal work, which was fundamental in finding the single lowest cost and efficient investment alternative. The approach considered five types of parameters for assessing energy portfolio for electricity generation. The parameters were technical, cost, financing, regulations and revenues. The study employed Monte Carlo simulations in order to obtain net present value and the optimal base load generation portfolios. Meanwhile, the generation portfolio for producing electricity considers nuclear, coal and combined cycle gas technologies.

This research coincides with methodologies undertaken by Awerbuch and Yang (2008), Delarue (2011).

F.3 *Mean Value Portfolio (MVP)* $= E(r_p) = \chi_i \cdot E(r_1) + \chi_2 \cdot E(r_2)$

The technical parameters took into consideration the net capacity, capacity factor, heat rate, carbon intensity, construction period, and plant life. The cost parameters took under advisement the overnight cost, incremental capital costs, fuel costs, real fuel escalation rate, fixed and variable operation and maintenance costs, operation and maintenance real escalation rate, as well as nuclear waste fee. As we had observed, previous function allows the analysis of two simple technologies portfolio regarding the expected returns. In this function $E(r_p)$ is the expected portfolio return, χ_i is the share of asset i in the portfolio, $E(r_1)$ is the expected return for asset i.

The financing parameters accounted real discount rate and marginal corporate tax. The regulatory parameters considered carbon taxes and carbon price escalation rate. Finally, the revenues parameters contemplated electricity price and electricity price escalation rate. For all the considered parameters their unitary measure was established for its easy evaluation and interpretation. This study allowed evaluating generation portfolios in order to determine the most efficient generation projects that can integrate an electricity matrix. Power generation capacities are elemental factors on assessing optimal energy mixes (Bunn 2004). However, the study was not complete, since it did not take into account other factors that can influence the real price of the electricity service in the markets. For example, it did not account the cost of electricity transmission infrastructure as well as transactional costs in the wholesale electricity market.

2.3.3 Pricing

Damigos, Tourkolias and Diakoulaki (2009) developed a descriptive-empirical research for assessing household's willingness to pay for safeguarding security of natural gas supply in electricity generation. Minimization techniques were utilized as well as the evaluation of several indicators. In one hand, the research identified basic indicators for measuring energy security, which were reflected into a basic statistics report. The identified factors were energy production, net imports, and gross consumption. Regarding the electricity industry it accounted the nominal installed capacity, total gross and net production of electricity. It considered the interconnected and non-interconnected systems. Natural gas consumption per industry or sector also was also accounted.

On the other hand, in order to assess the household's willingness to pay, a survey was carried out in order to collect data that contributed to accomplish the research. The survey was composed by two parts; from one side, it intended to collect information regarding the survey purpose; and from another side, it intended to collect demographic information. The results of the survey were analyzed under the contingent value method. The willingness to pay was assessing with a non-parametric analysis as well as a parametric analysis. This model is different than the one proposed by Kruyt et al. (2009) and Qureshi and Sonnsjö (2011). The nonparametric estimators evaluated payment modes through the use of data from the survey. The different prices of the payment methods were assessed in terms of acceptance (yes) or rejection (no). Bidding games also were considered and evaluated.

The utilized parametric analysis was a general empirical model in which the willingness to pay was the dependent variable and it subjected a set of model variables. These model variables were achieved also from the survey and assessed through using a Tobit model. Among the variables under study were the main types of fuels which were utilized for producing electricity. The knowledge of the households about the main types of fuels which were employed in producing electricity was accounted as well as to the information about environmental impacts and the knowledge of the inhabitants about it, and the willingness for reducing negative environmental impacts from households' side. At the same time, the environmental properties of one type of fuel compared with other were regarded and also the willingness to increase the electricity production from fuels which were environmentally friendly.

Table 2.8 Willingness to pay

Measurement	*Metric Formula*	*Acronyms' Meaning*
Tobit model for assessing willingness to pay (WTP)	$Y_i^* = \chi'_i\beta + \varepsilon_i$ $Y_i = \begin{cases} Y_i^*, \text{ if } Y_i^* > 0 \\ 0, \text{ if } Y_i^* \leq 0 \end{cases}$	Y_i is the WTP bid by individual i Y_i^* is the latent measure χ'_i are the explanatory variables of respondent i β is the vector coefficient of corresponding explanatory variables ε_i is the error term as independent normal with mean 0 and variance σ^2

Source: Damigos, Tourkolias and Diakoulaki (2009)

In this research among the demographic factors that were regarded are the expenses on electricity consumption, number of family members, level of education, residence area in square meters, and income. The study was limited at the households' scope. It contributed in assessing household's willingness to pay for safeguarding security of natural gas supply in electricity generation. Although it was a way to enclosure electricity supply it was not the optimal solution since prices tended to increase there would be also a decrease of social welfare for the inhabitants. The empirical methodology employed by the researchers was clear in the way that it was developed and accomplished as well as the way to present the results and their implications. However, it was required the analysis of more aspects that could change the normal behavior of prices and availability of the electricity service.

Badea et al. (2011) developed a research in order to establish composite indicators for measuring security of energy supply. The utilized approach is the ordered weighted averaging (OWA), which is based on the weighting and aggregation theory. The researchers' intention was to accumulate the data scheme in order to acquire a general level of options. The methodology is composed by three steps. The first one is determining a base value, which leads to establish well-structured ranks. Secondly, there is determined the OWA weights by find proper quantifier guided by aggregations. The authors supported their developments with the prior studies of Yager (1988); Kasai, Lalmas and Rolleke (2001); Diaz (2004). Finally, the scholars defined an OWA operator, which main function is to work as a map which employs weighting vectors in order to provide measurement values for what is being evaluated. In this case, it was supported by a previous research accomplished by Yager (1996).

The methodology developed by the researchers utilized a set of pre-established indicators for measuring energy security through their methodology regarding composite indicators. The method had the limitation that was employed just for the energy resources system. The factors that were considered affecting energy security for a given country were energy balances and issues related with power generation system performance. In this regard the study is limited because the researchers do not explain in detail the consulted indicators for the power generation system. Furthermore, the study is limited because it does not take into account the political, sociological, and technological factors as well as price issues affecting security of energy supply. These factors have a good influence on ensuring uninterrupted supplies of energy resources which are vital for the production of electricity and transportation at affordable prices. They argued that it was a limitation regarding data availability; however, their methodology can be used in assessing these other factors.

Rodilla and Batlle (2012) built a paper based on microeconomics theory for the development of their own model and to support their investigation where optimization techniques were utilized. The research accounted several equations in order to set the basic parameters for establishing optimal short-term prices. Among its components were variable costs in producing electricity, the quantity produced at specific times of the day, and the demand behavior. The study considered the operational technical constraints for the different generation utilities. Then the dual variables of the main constraints were settled. Their approach also allowed establishing the Lagrangian function in order to maximize the demand's function. Based on this methodology optimal quantity, prices, utilities, and benefits for both consumers and producers, as well the social benefits were obtained.

The study showed that in the case of the electricity industry at power generation level it did not fit with what the microeconomics theory set in order to achieve optimal conditions in the market. For the foregoing reasons a central planer and regulator, which commonly were the wholesale electricity marked as well as the regulatory institutions settled in deregulated markets need to develop policies and regulations in order to control unbalances in market operations. The developed model by the researchers intended to understand the dynamics of the electricity markets at the power generation level. Microeconomics theory is fundamental in supporting the study. At the beginning of the dissertation the researchers mentioned the instability of electrical infrastructure based on renewable energy resources and its influence on securing electricity supply. The methodology of this study is less extended and complete than the ones undertaken by Creti and Fabra (2007) as well as Schwenen (2011).

However, the investigation was limited in order to measure security of electricity supply since it only focused on prices and costs based on microeconomic theory. Therefore, it was important to make a deep analysis of situations and factors that can alter prices and availability of electricity. Finally, the study did not set which type of market was being analyzed in terms of number of competitors as well as the type of industrial organization that was considered. It just can be assumed that it was for a monopolistic model based on the employed model and formulas rather than the information provided by the scholars in their investigation.

2.4 Energy security in terms of acceptability

Landsea et al. (1996) and Pielke and Landsea (1999) employed a statistical methodology based on observation for understanding the frequency of natural phenomena such as La Niña and El Niño in the America's continent. The authors assessed information through using conventional statistics techniques such as the median, the mean and the variance. The researchers studied climate changes in the North Atlantic and Pacific Ocean. The study presented the economic losses created by hurricanes damages as well as droughts in the United States from 1925 to 1990. It emphasized that public infrastructure was subjected to be affected as well as productive activities. The study was limited to only consider the damages in the United States due to the natural phenomena. However, the methodology about monitoring the frequency of natural phenomena was important because it allowed identifying when water levels in rivers can exceed acceptable levels or may decline (Guikema et al. 2010). In addition biomass can diminish because of droughts (Long 1978). In both cases, abrupt changes in climate may have negative impacts on the electricity produced with any of these types of energy resources.

Sullivan and Huntingford (2009) employed a climate vulnerability index regarding Water resources, climate change and human vulnerability. However, this study does not estimate impacts over the electricity industry. On the other hand, Vergara et al. (2007) employed a qualitative-quantitative approach for measuring the consequences on watersheds' low hydrology. First at all, a watersheds' low hydrology can be produced by both the absence of rains as well as glacier retreat in mountains. The methodology allowed developing an equation for measuring the general hydrologic water mass balance. This function provided the water that was discharged in a basin. A basin can be integrated by several watersheds. The results showed the hydrological response to al climate changes. The main factor was the annual level of precipitation in each watershed. At the factor the water losses were subtracted from each watershed and the total change in the volume of water stored in the watershed through dams. The water losses were produced by water evaporation in the form of steam to the atmosphere because the heat of the sun over the earth.

F.4 *Hydrologic Water Mass Balance* $= Q = P - Et + \Delta S$

Where Q is the water discharge measured by a hydrometric station that integrates the basins hydrological response to all stimuli; P is the precipitation over the watershed; Et are the losses of water to the atmosphere due to evaporation of the resource; ΔS is the total change in the volume of water stored in dams. This methodology allowed establishing the negative impact of watersheds' low hydrology over the electricity industry. However the methodology was limited because it was mostly based on assumptions from the under study country. The methodology did not allow determining the reduction on the use of the installed power capacity as well as the number of megawatts hour (MWh) that will not be produced due to the lack of water (Guikema et al., 2010; Liu and Singh, 2010).

We considered that these impacts can be translated into monetary terms through quantify the cost of each MWh that was not produced domestically and compared and obtained the difference between these and the prices of each MWh produced with peak technologies or imported ones. The developed mathematical equation provided the volume of water precipitation over basins. However, in tropical countries it was not the volume the factor that has changed; in the other hand, the frequency and the intensity have been the factors which were not taken into account in this study.

Asif and Muneer (2007) employed a descriptive methodology, which put a statistical framework in order to analyze factors that can influence the security of energy supply negatively or positively. The elements that compose this scheme are the population of people in millions, population growth rate in percentage, which is a social fact. It is taken into account the gross domestic product per capita in monetary units and gross domestic product growth rate in percentage, which can be considered as economic factors. They considered as an environmental factor the CO_2 emissions in metric tons per capita. Finally, we found several factors that are part of the generation system. It is accounted energy consumption per capita in kilogram of oil equivalent, energy consumption per capita in kilowatts hour, and the total consumed energy, which is subdivided into the energy resources that are consumed such as coal, gas, oil, nuclear, and renewable. All of these factors were included in the research of Sovacool (2011a,b,c), which present a larger study concerning factors affecting the electrical industry.

Eilat, Golany, and Shtub (2008) proposed that technological innovation is the key driver for achieving energy security and environmental protection. Their methodology was based on employing business' benchmarking considering the apparent commercial success. However, there is other selected group of theorists, which argued in favor to consider beyond what has been proposed so far because in current business world environmental criteria must be addressed (Delmaset al., 2007; Acemoglu et al., 2011; Wiesenthal et al., 2012; Schmidt et al., 2012). Their opinions were based on the global warming effects which are changing the conditions to operate worldwide and the importance of reducing CO_2 emissions. They considered that technological innovations must be oriented in order to mitigate the negative effects that have been produced already over the environment as well as security of energy supply. However, none of them proposed how to measure environmental impacts affecting electricity supply in terms of power and energy that is not delivered.

For evaluating the level of dependence for oil and gas through the physical dimension, the net import as percentage of the total primary energy supply (TPES) was analyzed, and the share in a specific geographical area (Europe) for oil and gas imports of world's oil and gas imports in percentage. For assessing the level of vulnerability for oil and gas supply side through the physical dimension, it was possible to study the degree of supply concentration for trade, the degree of supply concentration for production, and the Shannon-Weiner diversity index. In addition the vulnerability for oil and gas demand side was evaluated throughout measuring the oil used for transportation in percentage, the share of electricity produced with gas in percentage, and the value of oil and gas consumed per capita.

With support of the formula employed by Solomon (2004) the researchers made up the consideration about measuring the impact of energy over environment. This formula considered population size (number of inhabitants), multiplied by the income per capita or energy use, and then multiplied by the energy efficiency factor in terms of environmental protection. This formula is employed to measure the impacts of energy industry producing CO_2 over ecosystems. They considered energy resources reserves as a measure of energy security in order to guarantee the supply of the commodities and stabilizing prices. Finally, it employed a more statistical framework in order to evaluate potential energy resources, demand's behavior, levels of supply, and achievements exploiting the potential energy resources. The factors that were considered and affecting energy security for a given country were the projected energy resources balances as well as demand and supply behaviors. The study is limited in terms to consider other factors that can provide a more complete overview in assessing energy security.

Due to the negative impacts that the use of fossil fuels have had on the environment, some policy makers have been concerned about addressing their targets to reduce pollution caused by CO_2 emissions through a shift on efficient energy matrices (Sun, 2003; Ürge-Vorsatz and Novikova, 2008; Timilsina, 2008; Pao and Tsai, 2010; Duan, 2010). Their main goal is to procure environmental sustainability. Furthermore, the diversification of energy sources requires technological acquisition, which is related with cost-effectiveness in order to make it possible (Sims et al., 2003; Kennedy, 2007; Ghosh, 2010; Kovacevic and Wesseler, 2010). We found that the methodologies of these theorists were connected with cost-effectiveness to reduce CO_2 emissions can be classified by industry, technology types, targets for CO_2 reduction, as well also with its contribution in achieving energy security.

This theory is also related with the achievement of specific targets, such as those established in the Kyoto's Protocol, through innovative technology utilization (Menanteau, Finon, and Lamy, 2003). However, it is important to note that no previous researcher has considered proposing the acquisition of new technologies and the environmental risks in diversifying the energy matrices. For the foregoing reasons we consider that there is a potential area of study which has not been covered already. Measures can be developed in order to establish negative environmental impacts on security of energy supply.

2.5 Lessons from literature review

In this Chapter we have seen that although there is an extensive literature regarding security of energy supply, still there is no prior study that undertakes energy security for the electricity industry through considering its supply chain and the core indicators that can influence continuity of electricity supply. We support our arguments based on what Chester (2010) said in favor, that it is required to develop more methodologies for quantifying security of energy supply in different fields and determining levels of statuses. Base on this, it is compulsory to set security levels for the electricity industry of a given nation. This author has recognized the challenges for assessing security of supply in the electricity industry. It has been as a result of the lack of consensus, among scholars and technicians from the electricity industry, in selecting a comprised number of indicators that can contribute in assessing energy security in this field.

Von Hippel et al. (2011) emphasized the need for developing better ways to summarize and visualize multiple energy security dimensions and attributes. According to the scholars, it must include tabular, statistical, and graphical methods. Winzer (2012) has claimed that the continuity of supply should be evaluated at different stages. It must involve the analysis of risks on the energy industries' supply chain, from the transformation processes of primary energy till end-user utility. Security of supply may be measured in terms of the continuity of the commodity supplies (oil, gas, coal or electricity).

Based on our research interests and findings along with the accomplished literature review, we believe that it is possible to ***contribute*** to develop a methodology for assessing the performance of the electricity industry's supply chain in terms of security of supply. We can contribute in improving prior methodologies[24] that were useful, but limited to assess energy security just in the energy resources system. We can expand them and apply that on the whole electricity industry's supply chain. The importance of developing a methodology is that it can be shared and used to evaluate the performance of the electricity industries in terms of energy security in other regions and countries around the world.

Our methodology compared with prior studies can contribute to establish security levels for the overall electricity industry and at the different systems level. We can set how secure are the energy resources

[24] Gupta (2008), Gnansounou (2008), Cabalu (2010), and Badea et al. (2011).

system, electricity generation system, as well as electricity transmission and distribution systems. This is a specific distinction of our research contrasted with others. All of these will be in harmony with the arguments that Chester (2010), Von Hippel et al. (2011), and Winzer (2012) have done regarding the things that are pendent to be covered in the field of research about energy security.

Chapter 3. Model

To assist in understanding the present study, the basic concept of energy security in the electricity sector is described as follows. Security is synonymous with certainty and guarantee, and it can be defined as the state in which a specific status can be reached or at least kept constant. Security provides certainty about achieving well-being for individuals and societies. This can include peace, food provision, health, wealth, living standards, the provision of public services as well as goods that support economic activities, etc. Human beings and societies by nature try to guarantee coverage without interruption of daily activities and support productive activities that are a prerequisite to improve or at least to maintain their current status. However, a constraint is the fact that coverage of daily needs and support for productive activities must be in accordance with their economic possibilities.

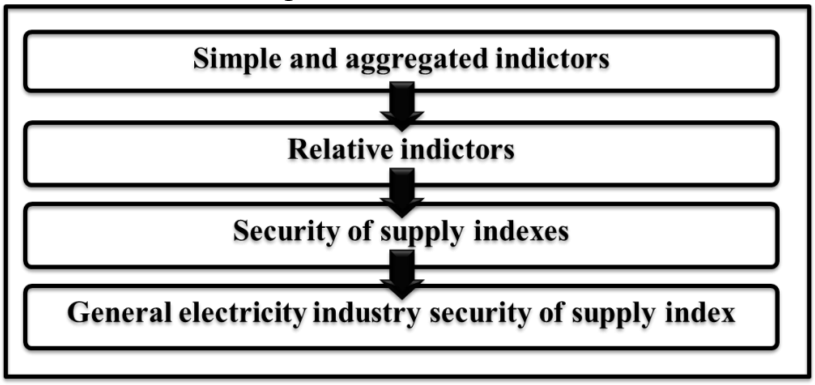
Energy security is a multidisciplinary concept from which emanates a set of policies, laws, regulations, and settled standards, as well as the actions that must be undertaken to ensure the supply of any energy commodity in accordance with demand for it. It has a wide range of interactions with other related disciplines. Security is synonymous with certainty, so energy security refers to the proper management of the internal and external factors that may affect the optimal performance of any sub-sector of the energy industry of a nation. Optimal performance means obtaining the required resources and the infrastructure for the provision of any kind of energy commodity.

The electricity industry must ensure the supply of electricity service without interruption and at affordable prices in accordance with the economic power of the inhabitants of a nation. In addition, it must have a positive impact on the society and the economy through support productive activities. Energy security at the electricity industry level must change the customary notion that claims that there is no electricity service more expensive than the one that cannot be had. In other words, energy security must achieve self-sufficiency and efficiency in delivering electricity service.

The electricity industry is important in terms of energy security since it is the supplier of the main resource used to produce goods and provide services within any national economy (Asif and Muneer 2005). In addition, it supports people's standards of living. If the electricity industry does not perform well because of interruptions in the provision of service or does not provide affordable prices, the national economy can be affected by a reduction in its gross domestic product and thus the country's wealth. On one hand, high electricity prices can negatively affect the main export-oriented industries, which can reduce competitiveness in the international markets. On the other hand, electricity shortages can affect the productivity of industrial, commercial, and agricultural firms as well as households by damaging household appliances (Aldana 2010). For example, in the United States, interruptions in the supply of electricity represent losses of around U.S. $80 billion annually (LaCommare and Eto 2004).

The electricity industry has become a business, in particular due to deregulation and the globalized economic processes. The business is susceptible to the effect of factors associated with firms' micro-environment as well as by factors associated with firms' macro environment. To accomplish our main research objective, it is necessary to develop a model for assessing supply security in the electricity industry. Figure 3.1 shows the logic that the proposed model aims to follow.

Figure 3.1 General model



3.1 Defining measurements

3.1.1 Single indicators

These are common measurements that allow understanding of the results or attributes of the activities performed within an industry's supply chain (OECD 2008). The single indicators are often linked to measurable outcomes during a specific period. For an indicator to be useful and effective, it has to meet a number of requirements, among which is relevance to the objectives of the industry. It has to be clearly defined to ensure the proper collection of information about it. It must be easy to understand and use and be comparable with the performance of similar industries over time. Finally, it must be easy to verify. For the aforementioned reasons, information about single indicators can be found in publicly annual statistical reports or databases.

3.1.2 Aggregated indicators

An aggregated indicator is a quantitative, qualitative, and descriptive measure of a state or progress toward an objective. These types of indicators are properties of a system that closely show or characterize its performance in relation to the performance requirement that has been set. These kinds of indicators can combine several single measurements into the application of a mathematical expression (OECD 2008). Their execution yields as the final product a single comprehensive view of a wide range of complex situations. They minimize the visible size of a set of indicators without dropping the underlying basic information. The use of this technique adds value in merging several measurements because the summary of the statistics captures different realities and is meaningful. These are tools that are easier to understand in comparison with an extensive set of separate statistical measurements, and they are helpful in assessing the achievements of any industry in a given nation over time.

3.1.3 Relative indicators

A relative indicator is a representation of a scaling technique in which the minimum value is set to 0 and the maximum to 1. The output of a given simple or aggregated indicator is evaluated within the interval of 0 to 1 (OECD 2008). It is a method used to standardize data contained in indicators. It is a process of normalizing data during transformation processes. One popular technique is rescaling the range of features to make them independent of each other with the intention to scale the range at [0, 1] or [-1, 1]. Depending on the nature of the investigation, the value of 1 is assigned to the indicator with a higher level of security and 0 is assigned to the indicator with the least level of security, or vice versa.

The output of an indicator can be normalized by deducting the minimum acceptable value regarding its performance. Then, the obtained result is divided by the difference that is obtained from the marginal acceptable values regarding its performance. The function of the relative indicators based on rescaling technique assesses the potential risks of losing something valuable, evaluated against the potential to gain something valuable. In this regard, standards are employed to assess the effects of potential risks to the security of public service delivery.[25]

3.1.4 Composite indicators (Indexes)

These are statistical measurements of the changes in a representative group of indicators. They are numbers that encompass the estimation of a collection of several indicators through the application of a mathematical expression. An index is used as a benchmarking tool to measure the relative performance of several single or aggregated indicators at the same time. The indexes summarize a complex range of information

[25] Water Security for Better Lives. ISBN 978-92-64-202405. OECD (2013). Page 1.

contained in several relative indicators (OECD 2008). They also minimize the visible size of a set of indicators without dropping the underlying basic information. These tools allow an understanding of complex situations in comparison with the use of an extensive set of separate statistical indicators. They enable the assessment of the performance of a given industry in any country over time.

3.2 Supply security index model description

The supply security index model is a high-level performance metric that is used to simplify complex information and point to the general state or trends of a situation. We aimed to fit any selected single or aggregated indicator into a relative indicator in each of the systems that compose the electricity industry's supply chain. The relative indicators are to be evaluated into the margins of the minimum and maximum values of standards and concepts from economic theory that are generally applicable to the operations of the different systems that make up the electricity industry's supply chain. The specification of the relative indicators is represented by the following equation:

$$\chi_{ijk} = [(I_n - \mathrm{Min}\ (I_n)) \div (\mathrm{Max}\ (I_n) - \mathrm{Min}\ (I_n))] \qquad (1)$$

χ is a relative indicator belonging to the system under study, represented by the subscript *i*, *j* specifies the country, and *k* indicates the time period. The variable I_n involves the output of a simple or aggregated indicator that can be selected for testing the model, while Min (In) and

Max (In) are the minimum and maximum values[26] allowed by standards or concepts from economic theory in the desired performance of a given simple or aggregated indicator.[27] In this study, the relative indicators are estimated by using a rescaling technique in which the minimum value is set to 0 and the maximum to 1. The value of 0 is assigned to the indicator with the lowest level of threats, while a value of 1 is assigned to the indicator with the highest level of risk. In addition, it is required that the values obtained for each relative indicator fall into the margins of the mathematical constraint, represented as:

$$\mathbf{0 \leq \chi_{ijk} \leq 1} \qquad \textbf{(2)}$$

The constraint is employed because some values from the relative indicators might fall below 0 or above 1. Our aim is not to affect the sensitivity that must be reflected by the values of our supply security indexes in indicating security levels, and for on this reason, the values between the ranges referred to can be captured. Its computation can be performed using a spreadsheet application in which the "if" function is available. It will be easy to understand and apply in analyzing the electricity industry's supply chain through maintaining the use of the same methodology, which can be combined to obtain a general supply security index (Aldana and Kim 2013).

[26] OECD. 2008. "Handbook on Constructing Composite Indicators: Methodology and User Guide." OECD Publications. Page 85.
[27] Hanssona et al. (2009) employed standardized values for assessing the performance of specific operations in tractor engine emissions.

We can develop a set of new analytic indexes for assessing supply security in each system of the electricity industry's supply chain. It is a counterpart initiative to the composite vulnerability indexes employed previously by Gupta (2008), Gnansounou (2008), and Cabalu (2010), which were referred to in Chapter 2, Table 2.3. We aimed to modify and expand the use of previous models focused on measuring vulnerabilities in the energy resource system or electricity generation system. This may be possible through defining our composite index as one minus the root mean square of the average results of our relative indicators for each system, which is divided by number of relative indicators (*n*),[28] and it is represented by the following equation:

$$\mathbf{SSI}_{ijk} = \mathbf{1} - \sqrt{}\,\left(\left(\sum_{ijk\,=\,1}^{4} \chi_{ijk}^{2}\right) \div n\right) \qquad \textbf{(3)}$$

By including 1- before the equation, we are modifying and expanding the use of this method, in contrast with Gupta (2008), Gnansounou (2008), and Cabalu (2010), because all of these authors were focused on measuring vulnerability levels instead of security. In this study, the number 1 represents the highest supply security level from which insecurity (threat) levels are deduced. χ is the representative relative indicator for the system *i* in country *j* during year *k*. Finally, based on our accomplishments, we can define our method as one minus the root mean square of the average results of our number of relative indicators (*n*) that

[28] Based on data availability and according to the country's features and its electricity industry's structure (Aldana and Kim 2013).

compose a given system *i* in country *j* during year *k*, and then it is divided by its number of relative indicators (*n*).

3.3 Developing composite supply security indexes

There is a need to develop composite indexes that can measure and assess supply security across the entire electricity industry's supply chain. Our purpose is to evaluate at the same time several relative indicators, corresponding to a given system, to assess security levels. Furthermore, they are useful tools for benchmarking security levels in the electricity industries of Latin American countries with regard to their respective efforts to manage risks.

3.3.1 Energy resource system supply security index

We define energy resources system security of supply index (RSSSI) as the of the energy resource system security output for a given nation *j* during year *k*. It represents the system's security level. It can be obtained by employing equation 3. This index is represented by the following equation:

$$\mathbf{RSSSI = 1 - \sqrt{\left(\left(\sum j_i^4 {}_{=1} \chi R_{jk}^2\right) \div 4\right)}} \qquad \mathbf{(4)}$$

The indicator RSSSI is defined as one minus the root mean square of the average results of our four relative indicators that compose the energy resource system, and then it is divided by the number of relative indicators (*n*). χR represents the representative relative indicators for the energy resource system in country *j* during year *k*. The relative indicators for this system are addressed in the next chapter.

3.3.2 Electricity generation system supply security index

We define the electricity generation system security of supply index (GSSSI) as the of the electricity generation system security output for a given nation *j* during year *k*. It represents the system's security level. It was found by employing equation 3. This index is represented by the following equation:

$$\mathbf{GSSSI = 1 - \sqrt{\left(\left(\sum j_{i}^{4}{}_{=1} \chi G_{jk}^{2}\right) \div 4\right)}} \qquad \mathbf{(5)}$$

The indicator GSSSI is defined as one minus the root mean square of the average results of our four relative indicators that compose the energy resource system, and then it is divided by the number of relative indicators (*n*). χG accounts for the relative indicators for the electricity generation system in country *j* during year *k*. The relative indicators for this system are addressed in the next chapter.

3.3.3 Electricity transmission and distribution systems supply security index

We define the electricity transmission and distribution systems security of supply index (TDSSSI) as the of the electricity transmission and distribution systems security output for a given nation *j* during year *k*. It represents the system's security level. It was found by employing equation 3. This index is represented by the following equation:

$$\textbf{TDSSSI} = \mathbf{1} - \sqrt{\left(\left(\sum j_{i=1}^{4} \chi \boldsymbol{T}\&\boldsymbol{D}_{jk}^{2}\right) \div 4\right)} \qquad \textbf{(6)}$$

The indicator TDSSSI is defined as one minus the root mean square of the average results of our four relative indicators that compose the energy resource system, and then it was divided by the number of relative indicators (*n*). In this study, this index comprises the electricity transmission and distribution activities in only one system. χT&D represents the representative relative indicators for the electricity transmission and distribution systems in country *j* during year *k*. The relative indicators for this system are addressed in the next chapter.

3.3.4 Electricity industry supply security index

Finally, our set of composite indexes for each of the systems that compose the electricity industry's supply chain can be integrated into a general composite supply security index, which aims to assess the overall performance of the industry in terms of supply security. It is called the electricity industry supply security index (EISSI), and it is represented by the following equation:

$$\textbf{EISSI} = \sqrt{([(\chi \boldsymbol{RSSSI_{jk}^{2}})^{2}+(\chi \boldsymbol{GSSSI_{jk}^{2}})^{2}+(\chi \boldsymbol{TDSSSI_{jk}^{2}})^{2}] \div 3)} \qquad \textbf{(7)}$$

EISSI is the output for the electricity industry supply security index. It is defined as the root mean square of the average results of our relative indicators for each, which is divided by three in this investigation because both the electricity transmission and distribution systems have been incorporated into a single system. RSSSI represents the composite indicator for the energy resource system in terms of supply security. GSSSI represents the composite indicator for the electricity generation system in terms of supply security. TDSSSI represents the composite indicator for the electricity transmission and distribution systems in terms of supply security. The subscript *j* specifies a given country, while *k* indicates the time period. However, it is important to mention that, if the electricity distribution system is going to be accounted for independently, it will be necessary to divide equation 7 by four.[29]

3.4 Differences from other studies and contributions

As noted, our model differs from those employed by Gupta (2008), Gnansounou (2008), Cabalu (2010), and Badea et al. (2011) because we

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[29] It can be divided by the number of systems (n) if the method is employed in measuring supply security in different industries with large-scale systems.

have modified and expanded the ones used in their research studies with the aim of assessing supply security levels throughout the electricity industry's supply chain. We have improved their useful methodologies but assess vulnerability levels only in the energy resource system or in the electricity generation system. Even if our target was not to assess vulnerability levels, our model is open to provide a picture of these kinds of situations from the potential relative indicators that can be tested before being transformed and incorporated into security index models.

Furthermore, our methodology, in contrast to those of prior studies, can help in establishing security levels for the electricity industry overall and at the levels of different systems. We can set how secure the energy resource system, electricity generation system, and electricity transmission and distribution systems are. This is a specific distinguishing feature of our research in contrast with others. Our proposal is in harmony with the arguments that Chester (2010), Von Hippel et al. (2011), and Winzer (2012) made, about the fields that have not been covered yet regarding energy security.

The conception of our model on these bases allowed us to develop a new quantitative method for assessing energy security levels in the electricity industry's supply chain.[30] By these means, we contribute to knowledge of the electricity industry as well as academia. The importance of developing this methodology is that it can be shared and used to evaluate the performance of the electricity industries in terms of energy security in other regions and countries around the world.

[30] von Hippel et al. (5, 2011).

We chose this methodology because it is more value-objective-oriented in comparison with other methodologies that are subjective and allocated less reasonable values. We intended not to allocate less reasonable values into the approach that can compensate inefficiencies in failing to comply with standards in certain activities of a particular system. Furthermore, our model is supported on the basis of principal component analysis theory, in which a composite indicator (index) is obtained as the Euclidean distance to the best security level, represented by one point. The Euclidean distance was standardized through our equation number 2, which serves as a constraint or parameter and yields values between zero and one.

Chapter 4. Data and Model Integration

This chapter starts by presenting the data and the limitations in obtaining statistics from electricity industries in other countries or regions around the world. We proceed with the theoretical framework that gave us the required guideline in selecting indicators to assess energy security in the electricity industry's supply chain. Then, the selected indicators are described and presented with respect to how they fit into their respective relative indicators, including the consideration of standards or concepts from economic theory. Finally, we conclude this chapter with the integration of our relative indicators into their composite supply security indexes.

4.1 Data

Most of the selected Latin American countries deregulated their electricity industries during the 1990s, and most of the available statistical information has been collected since 2000. This research paper covers the period from 2000 to 2011, for which most data is available for the selected indicators. Baca (2004, 81) stated that at least ten years is required to analyze the changes and effects in some areas under study. On one hand, data for testing our relative indicators in the supply security indexes were collected from annual statistical reports of electricity market operators, regulatory bodies, and ministries associated with energy issues, as shown in Appendix one. Table 4.1 presents the summary and definitions of our data.

Table 4.1 Definitions, measures and sources for selected indicators

Relative Indicator	***Definition***	***Measure***	***Source***
χR1	Reserves to production ratio	Decimal value between 0 to 1	* GO, RA, MO
χR2	Energy security index (price – regional)	Decimal value between 0 to 1	Own estimation with the support of OECD, GO, RA, MO
χR3	Energy resources imports dependency to produce electricity	Decimal value between 0 to 1	* GO, RA, MO
χR4	Energy mix diversification to produce electricity	Decimal value between 0 to 1	* GO, RA, MO
RSSSI	Energy resources system security of supply index	Decimal value between 0 to 1	Own estimation
χG1	Electricity imports dependency	Decimal value between 0 to 1	* GO, RA, MO
χG2	Reserves capacity factor of power plants	Decimal value between 0 to 1	* GO, RA, MO
χG3	Effective installed capacities of power plants	Decimal value between 0 to 1	* GO, RA, MO
χG4	Infrastructure aging factor of power plants	Decimal value between 0 to 1	* GO, RA, MO
GSSSI	Electricity generation system security of supply index	Decimal value between 0 to 1	Own estimation
χT&D1	Utilization factor of transformer s	Decimal value between 0 to 1	* GO, RA, MO
χT&D2	Utilization factor of power lines	Decimal value between 0 to 1	* GO, RA, MO
χT&D3	Losses factor	Decimal value between 0 to 1	* GO, RA, MO
χT&D4	Power factor	Decimal value between 0 to 1	* GO, RA, MO
TDSSSI	Electricity transmission and distribution systems security of supply index	Decimal value between 0 to 1	Own estimation
EISSI	Electricity industry security of supply index	Decimal value between 0 to 1	Own estimation

GO: ministries related with energy issues; RA: regulatory agencies; MO: market operators

4.1.1 Limitations in Obtaining Data from other Countries

Our supply security index models are not limited to employment in the assessment of energy security in the electricity industries of other countries or regions around the world. The model can be adjusted with the use of more or fewer indicators. The limitations in terms of data accessibility concern privacy, at least for the electricity distribution and distribution systems, language, market structures when a nation has several electricity markets and hundreds of participants due to its vast territorial range, and political regimes that can be closed to private investments. These were the limitations we found in conducting a wider international research study. Table 4.2 presents the barriers in accessing data in some interesting electricity industries around the world.

Table 4.2 Barriers in accessing data in other countries or regions

Country/ Limitation	Data Privacy for at least 1 system	Language Barriers	Wide Geography of the Country	Market Structure (several regional markets)	Political Regimen (closed to private participation)
Brazil		●	●	●	
China	●	●	●	●	
EU-28	●	●		●	
Japan	●	●		●	
Korea	●	●			
Russia	●	●	●	●	
United Kingdom	●				
United States	●		●	●	
Venezuela	●				●

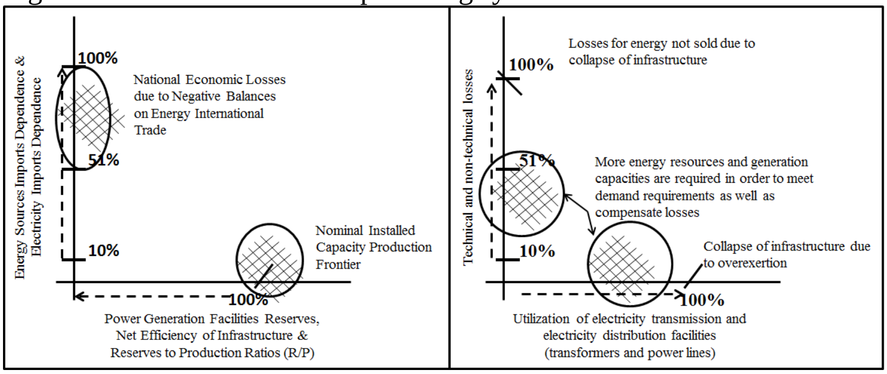
Sources: ANEEL (2013); SERC (2013); Eurostat (2013); CEER (2013); KEPCO (2013); KOREC (2013); FTS (2013); OFGEM (2013); FERC (2013);); CORPOELEC (2013); AFURNET (2013

Because of the situations described in the table above, we selected the chosen 12 Latin American nations because the data availability, accessibility, and timing suited our research interests. The limitations in accessing data can result from the fact that many countries around the world are careful in publishing detailed information about their energy resource system and about their electricity transmission and distribution systems. This type of information can be considered in domestic security policies because its publication might discourage investments when the performance of the systems is not the optimal to support productive industries. However, we believe that data can be obtained, and our methodology can be implemented through consultancy in agreement with national regulatory agencies or congressional energy commissions interested in assessing the performance of their domestic electricity industry in terms of supply security.

4.2 Theoretical Framework for Selecting Indicators

Energy security in the electricity industry encompasses four areas: availability, accessibility, acceptability, and affordability. Our proposal is formulated under considerations regarding supply security that were made for several research studies either individually or in conjunction with others, as well as studies for specialized research institutions. They were interested in addressing measurements regarding supply insecurity or threats affecting the delivery of electricity supplies. Figure 4.1 shows the intrinsic relationships among and potential threats to the systems that compose the electricity industry's supply chain.

Figure 4.1 Intrinsic relationships among systems and indicators



Based on the insights provided in the figure above, we can argue that there is a "chain effect" as a consequence of lacking sufficient energy resources as well as infrastructures to produce and deliver electricity service. Furthermore, inefficiencies in complying with operational standards can affect the performance of the systems that compose the electricity industry's supply chain. The selected indicators are presented below, and they were based on four basic principles. First, we followed the inherent relationships among systems that were presented in Figure 4.1. Then, we selected indicators that fit those relationships to assess the industry's supply chain performance. The indicators were selected according to the dimensions of energy security described in the literature review. Finally, we considered technical standards as well as concepts from economic theory that can provide robustness to our approach (Hanssona et al., 2008).

4.2.1 Selected indicators for the energy resource system

A nation may face challenges in producing electricity because of a lack of energy resources due to geological conditions, a lack of facilities for transforming the resources, or inaccessibility until the regions' resources were located. For nations owning energy resources, it can result from a decline in their proven reserves. In the presence of these conditions, the electricity industry will start to shift its energy mix (technological infrastructure change), selecting suppliers of energy commodities and importing energy sources from foreign trading countries. The prices of energy commodities on the international markets are susceptible to price volatility as a consequence of shocks to the macro environment (Fisher and Rothkopf, 1989; Stoner et al., 1995; Hill, 2007; Kolos and Ronn, 2008).

4.2.1.1 Reserves to production ratio (RPR)

The reserves to production ratio represent the lifespan of an energy resource in terms of years. According to the literature considered in this study, this indicator is related to the availability of energy resources. It was employed in previous research studies by Moroney and Berg (1999), Bartlett (2000), and Feygin and Satkin (2004). We have included this indicator because it indicates whether a given country owns energy resources and whether it has conducted exploration and exploitation activities. This indicator was considered in the research of Asif and Muneer (2007), which addresses energy supply, its demand, and security issues for developed and emerging economies. The author conducted a descriptive study supported with statistical data.

In our research, we aimed to expand the use of this indicator to the electricity industry's supply chain by transforming this measurement into a relative indicator based on standards and concepts from economic theory. Our final goal was to incorporate the relative indicator into an index for assessing supply security in an energy resource system. The technical-economic consideration employed is that the development of energy projects for oil and gas fields, coal and uranium mines, and hydro power plants requires at least 10 years to be implemented (Moroney and Berg, 1999; Bartlett, 2000; Feygin and Satkin, 2004; International Atomic Energy Agency, 2005).

***F.7* RPR = Proven Reserves ÷ Annual Production**

Both proven reserves and annual production correspond to the amounts of energy resources, expressed in kiloton oil equivalent (KTOE), that are employed exclusively in the production of electricity.

Relative indicator

$$\chi R_1 = \frac{\text{RPR} - \text{Min (10 years)}}{\text{Max } (+\infty \text{ years}) - \text{Min (10 years)}}$$

For this indicator, we considered that, if the output is zero, the level of threats will automatically be the highest value of 1 since it cannot fulfill the developed standards or concepts from economic theory. In addition, when the output is lower than the minimum settled value in its correspondent standard or concept from economic theory, it will be negative, and for the aforementioned reasons it needs to be summed to 1, but it only applies if the output ranges between -0.99 and -0.01. Finally, if we have a case where the output from the relative indicator is a value higher than -1.0, it needs to be multiplied by -1.

It is required that the values obtained from the relative indicator fall into the margins of the mathematical constraint expressed in equation 2 of chapter three. By performing these procedures, we are modifying and expanding the use of this scaling technique, in contrast with Gupta (2008), Gnansounou (2008), and Cabalu (2010), because in their cases, standards or concepts from economic theory were not employed. In this study, their use compensates for negative outcomes resulting from the employment of standards and concepts from economic theory in weighting the single or aggregated measurement within its relative indicator. Furthermore, it helps in determining a more realistic level of threat from the relative indicator.

4.2.1.2 Energy security index price—regional (ESIprice_regional)

The energy security index price—regional shows a price vulnerability index due to market power as well as social, political, and economic decisions. According to the literature considered in this research, this indicator is related to the affordability of energy commodities. The original indicator was proposed by the IEA (2007), and Lefèvre (2010) conducted a research study regarding measuring the energy security implications of fossil fuel resource concentration. In their cases, it was used to assess the price vulnerabilities in competitive markets and focus on the resource system's performance. However, we aimed to expand the use of this indicator to the electricity industry's supply chain through transforming this aggregated measurement into a relative indicator based on standards and concepts from economic theory. Our final goal is to put the relative indicator into an index for assessing supply security in the energy resource system to include it in a composite index for assessing supply security in the energy resource system. In addition, we aimed at expand the use of this indicator to the electricity industry's supply chain.

The technical-economic consideration employed is that the nations under study should not import more than 10% over total energy supplies to produce electricity since they have the potential to develop own energy projects. However, in the case of trade, the buyers should have at least three different suppliers, and the country risk rating should not be higher than 4 points out of a total of 7 (OECD, 2012; IEA, 2007; Wickens, 2008; Allen et al., 2010; Arnold, 2011). In addition, in our research, we use regional market shares since the nations under study trade in duopolistic regional markets because of proximity among suppliers and buyers as well as freight costs. Furthermore, the country risk analysis was carried out with the classifications of the participants in accordance with the arrangement on officially supported export credits from the OECD (2012).

$$\textit{F.8}\ \mathbf{ESI_{price(regional)}} = \boldsymbol{Pij{*}(Cf{\div}}\mathbf{TES)}$$

P is the market share of supplier *i* for fuel *j* multiplied by the country risk rating for the country of origin of supplier *i*, and *Cf* is the share of fuel *j* divided by the total energy supply (TES) for the importing country. Fuel *j* is imported just for producing electricity. In cases with more than one supplier of energy commodities, the country risk rating can be estimated as the average risk of all the suppliers, proportionally to their supplied quotas.

Relative indicator

$$\boldsymbol{\chi}\mathbf{R_2} = \quad \underline{\mathbf{ESIprice(regional) - Min\ (0)}}$$

Max (200) – Min (0)

4.2.1.3 Energy resource imports dependency (ERID)

Energy resource imports dependency determines the levels of dependency on imported energy commodities to produce electricity. According to the literature considered in this study, this indicator is related to the accessibility and acceptability of both energy commodities and installed capacities to produce electricity. This indicator was considered in Kruyt et al. (2009) regarding indicators for energy security. The researchers employed an import dependency indicator that applies a combined measure of diversity and import dependence criteria based on the Shannon index to measure an economy's import dependence weighted with its fuel diversity. In the case of Kruyt et al. (2009), their research was aimed to cover the total energy supplies and not the electricity industry in particular, as it is our case. We are interested in energy imports that are used to produce electricity, and for the aforementioned reasons, we based our indicator on the one suggested by Sovacool and Mukherjee (2011), which is a simple indicator regarding quantities of imported energy resources to produce electricity (Sovacool and Mukherjee, 2011).

However, in our research, we aimed at expanding the use of this indicator to the electricity industry's supply chain through transforming the measurement into a relative indicator based on standards and concepts from economic theory. Our final goal is to put its relative indicator into an index for assessing supply security in the energy resource system. The economic theory sets the optimal level of dependency at 0% because it denotes self-sufficiency, while the maximum recommended is 10%. This criterion is set because the most desirable state is self-sufficiency to avoid negative effects on prices in supplying electricity as well as at the macroeconomic level (Mukherjee, 2002; Urízar, 2007; IEA, 2007; Wickens, 2008; Allen et al., 2010; Arnold, 2011).

$$\textbf{\textit{F.9}}\ \mathbf{ERID = ERI \div TES}$$

ERI is the amount of resource i imported for producing electricity, while TES is the total energy supply.

Relative indicator

$$\chi R_3 = \frac{ERI - Min\,(0\%)}{Max\,(10\%) - Min\,(0\%)}$$

4.2.1.4 Energy mix diversification (EM)

This indicator accounts for the amounts of each type of energy resources that are used to produce electricity in a given nation. According to the literature considered in this research, this indicator is related to the accessibility and acceptability of energy commodities and installed capacities to produce electricity. It contributes to the determination of fuel mixes and reflects the type of technologies employed for producing electricity (Sovacool and Mukherjee, 2011; von Hippel et al., 2011). It was employed previously by Grubb et al. (2006) and was based on the Herfindahl–Hirschman index. Their research aimed to evaluate energy mix diversification for the electricity generation system of the United Kingdom, and it was supported with the use of statistical data. In our research, we aimed at expanding the use of this indicator to the electricity industry's supply chain through transforming this measurement into a relative indicator based on diversification and equality principles.

Our final goal is to put its relative indicator into an index for assessing supply security in the energy resource system. The energy mix diversification indicator should account at least 3,333 shares to reduce the risk of dependency (Mukherjee, 2002; Urízar, 2007; IEA, 2007; Wickens, 2008; Allen et al., 2010; Arnold, 2011; Mankiw, 2012). This value represents an identical level of use for three different energy resources in electricity production.

$$\textbf{\textit{F.10}}\ \mathbf{EM} = \sum_i \mathbf{S}_{if}^{\ 2}$$

S is the share of each energy source *i*, defined the by type of technology *f*, that is employed for producing electricity, especially fossil fuels.

Relative indicator

$$\chi\mathbf{R}_4 = \frac{\mathbf{EM} - \mathbf{Min\ (0)}}{\mathbf{Max\ (3333) - Min\ (0)}}$$

Concerning the energy resource system, we aimed to obtain data regarding storage capacities, utilization factor capacities in production and pipelines, and losses in the transformation of energy resources into commodities. However, not all our selected nations are producers of hydrocarbons, or they may not publish the information regarding those indicators. This type of data can be considered part of domestic security policies because its publication might discourage investment in the general economy when the performance of the system is not optimal to support productive industries. However, we believe that data can be obtained and that our methodology can be implemented through consultancy in agreement with ministries of energy and mines, regulatory agencies, or congressional energy commissions interested in assessing the performance of their domestic industry in terms of supply security.

4.2.2 Selected indicators for the electricity generation system

Electromechanical infrastructures have a nominal installed capacity, which is subjected to the restrictions developed by economic theory (Allen et al., 2010; Nicholson, 2010). Operational efficiencies are subject to the lifespan of the equipment as well as the operation and maintenance programs. The lack of infrastructure to produce electricity service domestically can lead to the absence of reserves capacities and an escalation in electricity import dependency. Nations commonly seek to establish electrical bilateral interconnections to solve their problems. In addition, to satisfy consumption demand and solve problems in the development of indigenous renewable energy resources because the negative effects from external factors (social, economic, political, environmental, etc.), electricity industries can diversify their energy mix to produce electricity. It involves the adoption of thermal power technologies with different efficiency levels.

A single-cycle steam turbine power plant has been the most widespread type of technology since the 20th century, and international trade has provided a solution for countries lacking energy resources and capacities (Rose and Joskow, 1990). However, these kinds of technologies are well known because they have a short life cycle and low operational efficiency levels in comparison with hydropower technologies or combined-cycle gas turbines (CCGT) (Wright, 2005; Nooij et al., 2007; Pérez, 2007; REKK, 2009; Paulus et al., 2011).

4.2.2.1 Electricity import dependency (ELID)

The electricity import dependency indicator represents the net quantities of electricity that are imported from neighboring countries. According to the literature, this indicator is related to the accessibility of energy commodities. This indicator was employed by Sovacool and Mukherjee (2011a) in their study on conceptualizing and measuring energy security. The same authors conducted an investigation to evaluate energy security performance (2011b). The latest study incorporated electricity imports in a general index regarding the total energy supply.

However, we aimed at expanding the use of this indicator to the electricity industry's supply chain through transforming this measurement into a relative indicator that can later be fitted into an index for assessing supply security in the electricity generation system. In accordance with economic theory, an optimal level of dependency is 0%, while the maximum recommended is 10%, because the most desirable state is self-sufficiency to avoid negative effects on prices in supplying electricity service (Mukherjee, 2002; Urízar, 2007; IEA, 2007; Wickens, 2008; Allen, et al., 2010; Arnold, 2011; Mankiw, 2012).

$$\textbf{\textit{F.11}}\ \mathbf{ELID = eli \div dprel}$$

ELID is the net amount of electricity imported, and *dprel* is the total amount of electricity produced domestically.

Relative indicator:

$$\chi G_1 = \frac{\text{ELID} - \text{Min (0\%)}}{\text{Max (10\%)} - \text{Min (0\%)}}$$

4.2.2.2 Reserves capacity factor (RCF)

The reserves capacity factor represents the power generation capacity that is available and can cover consumption demand increases. According to the literature, this indicator is related to the availability of energy commodities. This indicator was mentioned by Scheepers et al. (2006) as a part of the European Union standards for energy supply security. The authors reported the assessment of the performance of this indicator through their supply/demand index model, which uses shares of different types of supply and demand. We aimed to account for the reserve capacities expressed in shares as they suggested. However, in our research, we aimed to expand the use of this indicator to the electricity industry's supply chain. We aimed to transform this measurement into a relative indicator based on standards settled in Scheepers et al. (2006). Our final goal is to put the relative indicator into an index for assessing supply security in the electricity generation system. Based on their techno-economic criteria, 20% of available capacity is recommended as a maximum and 5% as a minimum. Beyond these margins is risky and might not meet demand.

F.12 **RCF = MPD ÷ NIC**

MDP is the maximum power demand expressed in MW, and NIC is the nominal installed capacity of the generation system expressed in MW.

Relative indicator:

$$\chi G_2 = \frac{\textbf{RCF} - \textbf{Min (5\%)}}{\textbf{Max (20\%)} - \textbf{Min (5\%)}}$$

For this indicator, we considered that, if the output is 0, the level of threats automatically will be the highest value of 1 since it cannot fulfill the developed standards or concepts from economic theory. In addition, when the output is lower than the minimum settled value in its correspondent standard or concept from economic theory, it will be negative, and for the aforementioned reasons, it needs to be summed to 1, but it only applies if the output ranges between -0.99 and -0.01. Finally, if we have a case where the output from the relative indicator is a value higher than -1.0, it needs to be multiplied by -1.

It is required that the values obtained from the relative indicator fall into the margins of the mathematical constraint expressed in equation 2 of chapter three. By conducting these procedures, we are modifying and expanding the use of this scaling technique, in contrast with Gupta (2008), Gnansounou (2008), and Cabalu (2010), because in their cases, standards or concepts from economic theory were not employed. In this study, their use compensate for negative outcomes resulting from the employment of standards and concepts from economic theory in weighting the single or aggregated measurement within its relative indicator. Furthermore, it helps in determining a more realistic threat level from the relative indicator.

4.2.2.3 Effective installed capacities (EIC)

The effective installed capacities account for the amounts of electricity produced in power plants that integrate the electricity generation system. According to the literature, this indicator is related to the availability of energy commodities. This indicator was mentioned by Scheepers et al. (2006) as a part of the European Union standards for energy supply security. The authors reported the assessment of the performance of this indicator through their supply/demand index model, which uses shares of different types of supply and demand. We aimed to account for the reserves capacities expressed in shares as they suggested. However, in our research, we aimed to expand the use of this indicator to the electricity industry's supply chain. We aimed to transform this measurement into a relative indicator based on the standards of Scheepers et al. (2006). Our final goal is to put the relative indicator into an index for assessing supply security in the electricity generation system. Based on their techno-economic criteria, the minimum level recommended is 80%, while the maximum level is 95%. Below the margins, the system operates inefficiently. Based on the criteria employed by Scheepers et al. (2006) regarding their supply/demand index model, which uses shares of different types of supply and demand, we are employing this indicator.

F.13 **EIC = AUF ÷ NIC**

AUF is the average use factor of the whole power plant system expressed in megawatts (MW), and NIC is the nominal installed capacity of the whole power plant system expressed in MW.

Relative indicator:

$$\chi G_3 = \frac{\text{EIC} - \text{Min (80\%)}}{\text{Max (95\%)} - \text{Min (80\%)}}$$

For this indicator, we considered that, if the output is 0, the level of threats automatically will be the highest value of 1 since it cannot fulfill the developed standards or concepts from economic theory. In addition, when the output is lower than the minimum settled value in its correspondent standard or concept from economic theory, it will be negative, and for the aforementioned reasons, it needs to be summed to 1, but it only applies if the output ranges between -0.99 and -0.01. Finally, if we have a case where the output from the relative indicator is a value higher than -1.0, it needs to be multiplied by -1.

It is required that the values obtained from the relative indicator fall into the margins of the mathematical constraint expressed in equation 2 of chapter 3. By performing these procedures, we are modifying and expanding the use of this scaling technique, in contrast with Gupta (2008), Gnansounou (2008), and Cabalu (2010), because in their cases, standards or concepts from economic theory were not employed. In this study, their use compensates for the negative outcomes resulting from the employment of standards and concepts from economic theory in weighting the single or aggregated measurement within its relative indicator. Furthermore, it helps in determining a more realistic threat level from the relative indicator.

4.2.2.4 Infrastructure age factor (IAF)

Infrastructure age factor accounts for the age of the power plants that integrate the electricity generation system. According to the literature, this indicator is related to the accessibility of energy commodities. It provides an overview of when infrastructure might collapse due to aging. It provides criteria on when further investments are needed to improve the electrical infrastructure. Sovaccol and Mukherjee (2011) considered this indicator part of operation and maintenance activities, which reflects the safety, reliability, and quality of infrastructure. We are adopting this indicator to measure potential risks. Furthermore, Rinaldi et al. (2001)

stated that electromechanical equipment in power plants work with a low probability of failure in the beginning, but its performance decreases over time in combination with the performance of the equipment, while the probability of failures increases gradually.

According to Rinaldi et al. (2001), the optimal level is the lowest age factor because efficiencies are higher at power plants and exposure to risks is low. For the aforementioned reasons, the maximum acceptable level is 80%, while the remaining lifespan allows the replacement of depreciated assets. In our research, we aimed to expand the use of this indicator to the electricity industry's supply chain. We aimed to transform this measurement into a relative indicator based on the technical criteria of Rinaldi et al. (2001). Our final goal is to put the relative indicator into an index for assessing supply security in the electricity generation system.

F.14 **IAF = AAPP ÷ AELPP**

AAPP is the average age of power plants and AELPP is their average expected life.

Relative indicator:

$$\chi G_4 = \frac{\text{IAF} - \text{Min (0\%)}}{\text{Max (80\%)} - \text{Min (0\%)}}$$

Concerning the electricity generation system, we aimed to obtain data regarding losses in producing the service. However, not all our selected nations publish information regarding this indicator. It might be because losses in electricity production are commonly below 5% or because of private policies when the system is deregulated, companies are publicly traded, and its publication might discourage investment. However, we believe that data can be obtained and that our methodology can be implemented through consultancy in agreement with ministries of energy and mines, regulatory agencies, or congressional energy commissions interested in assessing the performance of the domestic industry in terms of supply security.

4.2.3 Selected indicators for the electricity T&D systems

Electrical infrastructures have a nominal installed capacity, which is subject to the restrictions developed by economic theory (Allen et al., 2010; Nicholson, 2010). Equipment overexertion generates heat, yielding a low power factor, and it increases losses in the different systems. In the case of losses and to meet demand, the downstream systems (distribution and transmission) pull over the upstream systems (generation and resources). In this case, the losses are compensated for by demanding the employment of more power generation capacities as well as energy sources for electricity production. The utilization factor, the power factor, and the losses tend to be higher in the electricity distribution system in comparison with the electricity transmission system. This phenomenon occurs because the downstream industry, where end users are located, is more dynamic or unstable in terms of electricity consumption.

In the case of developing countries, the behavior of losses in both systems is dynamic because this type of country, as in the case of most of the nations studied in the present research, are still conducting missionary activities (García et al., 20011; Ghosh, 2012). For example, most of these countries are still undertaking rural electrification activities as well as expanding other basic infrastructure in the electricity transmission system.

The losses in the electricity distribution system are higher than those in the electricity transmission system. In addition, the rate of use for the electrical infrastructure in both systems tends to be superior for transformers than for power lines. These situations are an outcome of the nature of the downstream industry, in which electricity consumption behavior is more dynamic.

By failing to comply with standards in certain activities of a system, the risk of failures increases (Yeddanapudi, 2005). Later, it will increase the possibility of interruptions in supplying electricity to end consumers. Otherwise, when operating under compliance standards, the risk of failure in service delivery tends to diminish considerably. It is expected that the performance of the electricity industry can be linked to infrastructure's efficiency. Productive facilities by nature are subject to nominal capacities and life cycles and then to their production frontier (Allen et al. 2010; Nicholson, 2010). For the aforementioned reasons, further investments in infrastructure additions and timely maintenance are required to maintain or increase the security and continuity of the electricity supply. However, well organized planning[31] is required so that the improvement of one system does not affect the others.

4.2.3.1 Utilization factor of transformers (UftT&D)

The utilization factor of transformers accounts for the electricity power that is transformed in substations. Electrical equipment might fail

[31] A.K., David and Fushuan Wen. 2001. "Transmission planning and investment under competitive electricity market environment." IEEE Power Engineering Society 3: 1725-1730.

due to overexertion. According to the literature, this indicator is related to the availability of energy commodities. The infrastructure overload can be a consequence of increasing demand, and it can result in power outages (IEC, 2000, 2002; IEEE, 2002). According to the standards from the IEC, the minimum level of utilization recommended for both systems is 40%, while the maximum level recommended is 90%.

In our research, we aimed to expand the use of this indicator to the electricity industry's supply chain through transforming this measurement into a relative indicator based on standards of the IEC and the criteria employed by Scheepers et al. (2006) regarding their supply/demand index model, which uses shares of different types of supply and demand. For the aforementioned reasons, we are employing this indicator to achieve the goal of putting it into a relative indicator and then into an index for assessing supply security in electricity transmission and distribution systems.

F.15 **UftT&D = MaxCap ÷ NomCap**

MaxCap is the maximum power that can be supplied through the lines, which is expressed in MVA. NomCap is the nominal level of power that can be supplied through the lines, which is expressed in MVA.

Relative indicator:

$$\chi T\&D_1 = \frac{\text{UftT\&D} - \text{Min (40\% T\&D)}}{\text{Max (90\% T\&D)} - \text{Min (40\% T\&D)}}$$

For this indicator, we considered that, if the output is 0, the level of threats automatically will be the highest value of 1 since it cannot fulfill the developed standards or concepts from economic theory. In addition, when the output is lower than the minimum settled value in its correspondent standard or concept from economic theory, it will be negative, and for the aforementioned reasons, it needs to be summed to 1, but it only applies if the output ranges between -0.99 and -0.01. Finally, if we have a case where the output from the relative indicator is a value higher than -1.0, it needs to be multiplied by -1.

It is required that the values obtained from the relative indicator fall into the margins of the mathematical constraint expressed in equation 2 of chapter 3. By performing these procedures, we are modifying and expanding the use of this scaling technique, in contrast with Gupta (2008), Gnansounou (2008), and Cabalu (2010), because in their cases, standards or concepts from economic theory were not employed. In this study, their use compensates for the negative outcomes resulting from the employment of standards and concepts from economic theory in weighting the single or aggregated measurement within its relative indicator. Furthermore, it helps in determining a more realistic threat level from the relative indicator.

4.2.3.2 Utilization factor of power lines (UfplT&D)

The utilization factor of power lines shows the electricity that runs through power lines. The grid might collapse due to overexertion. According to the literature, this indicator is related to the availability of energy commodities. The overload on wires can be a consequence of increasing demand, and it can cause power outages supplying (IEEE, 2002; IEC, 2002, 2004a, 2004b, 2006). According to the standards from the IEC, the minimum level of utilization recommended for both systems is 40%, while the maximum level recommended is 90%.

In our research, we aimed to expand the use of this indicator to the electricity industry’s supply chain through transforming this measurement into a relative indicator based on standards of the IEC and the criteria employed by Scheepers et al. (2006) regarding their supply/demand index model, which uses shares of different types of supply and demand. For the aforementioned reasons, we are employing this indicator to achieve the goal of putting it into a relative indicator and then into an index for assessing supply security in electricity transmission and distribution systems.

F.16 **UfplT&D = MaxCap ÷ NomCap**

MaxCap is the maximum power that can be supplied through the lines, which is expressed in MVA. NomCap is the nominal level of power that can be supplied through the lines, which is expressed in MVA.

Relative indicator:

$$\chi T\&D_2 = \frac{UfplT\&D - Min\ (40\%\ t\&d)}{Max\ (90\%\ t\&d) - Min\ (40\%\ t\&d)}$$

For this indicator, we considered that if the output is 0, the level of threats automatically will be the highest value of 1 since it cannot fulfill the developed standards or concepts from economic theory. In addition, when the output is lower than the minimum settled value in its correspondent standard or concept from the economic theory, it will be negative, and for the aforementioned reasons, it needs to be summed to 1, but it only applies if the output ranges between -0.99 and -0.01. Finally, if we have a case where the output from the relative indicator is a value higher than -1.0, it needs to be multiplied by -1.

It is required that the values obtained from the relative indicator fall into the margins of the mathematical constraint expressed in equation 2 of chapter 3. By performing these procedures, we are modifying and expanding the use of this scaling technique, in contrast with Gupta (2008), Gnansounou (2008), and Cabalu (2010), because in their cases, standards or concepts from the economic theory were not employed. In this study, their use compensates for the negative outcomes resulting from the employment of standards and concepts from economic theory in weighting the single or aggregated measurement within its relative indicator. Furthermore, it helps in determining a more realistic threat level from the relative indicator.

4.2.3.3 Losses factor (LfT&D)

The losses factor accounts for the amount of electricity that is lost in electrical equipment in transmission and electricity distribution systems. It accounts for both technical and non-technical (theft of electricity) issues. According to the literature, this indicator is related to the accessibility of energy commodities. We have selected this indicator because it is a measure of operational efficiency (IEC, 1993-2011, 1999). According to the standards from the IEC, it is not feasible to achieve 0% losses. The recommendation of the standard is that the levels of loss not exceed 15% for the transmission system and 10% for the distribution system. In our research, we aimed to expand the use of this indicator to the electricity industry's supply chain through transforming this measurement into a relative indicator based on standards of the IEC and the criteria employed by Scheepers et al. (2006) regarding their supply/demand index model, which uses shares of different types of supply and demand. For the aforementioned reasons, we are employing this indicator to achieve the goal of putting it into a relative indicator and then into an index for assessing supply security in electricity transmission and distribution systems.

$$F.17\ \mathbf{LFt\&d = [}\boldsymbol{Et - Ed - Ex}\mathbf{]\div 100}$$

Et is the amount of electricity transferred through electricity transmission and distribution systems expressed in terawatt hours (TWh), gigawatt hours (GWh), or megawatt hours (MWh). *Ed* is the amount of electricity delivered by electricity transmission and distribution systems expressed in TWh, GWh, or MWh. *Ex* is the exports of electricity expressed in TWh, GWh, or MWh.

Relative indicator:

$$\chi T\&D_3 = \frac{LFt\&d - Min\ (0\%\ LFt\&d)}{Max\ (15\%\ LFt\&d) - Min\ (0\%\ LFt\&d)}$$

4.2.3.4 Power Factor (PfT&D)

The power factor represents the real power flowing to the load and to the apparent power in the circuits. According to the literature, this indicator is related to the accessibility of energy commodities. We have included this indicator because, according to international standards, a low power factor means losses in the production and conduction processes of electricity delivery to the end customers (IEC, 2000-2005). Furthermore, according to Reid (1996) and Vinnal et al. (2010), the quality of the power factor also affects the voltage quality as well as the harmonics (frequency). For the aforementioned reasons, the power factor is the optimal representative indicator regarding voltage quality issues. According to the standards from the IEC, it is desirable to adjust the power factor of the electricity transmission and distribution systems to near 1.0.

In our research, we aimed to expand the use of this indicator to the electricity industry's supply chain through transforming this measurement into a relative indicator based on standards of the IEC and the criteria employed by Scheepers et al. (2006) regarding their supply/demand index model, which uses shares of different types of supply and demand. For the aforementioned reasons, we are employing this indicator to achieve the goal of putting it into a relative indicator and then into an index for assessing supply security in electricity transmission and distribution systems.

***F.18* PfT&D = P ÷ |S| = cos (Φ)**

P is real power (active power) measured in watts (W). *S* is the apparent power measured in volt-amperes (VA). Finally, Φ is the reactive power measured in reactive volt-amperes (VA).

Relative indicator:

$$\chi T\&D_4 = \frac{LFt\&d - Min\,(0.9\,LFt\&d)}{Max\,(1.0\,LFt\&d) - Min\,(0.9\,LFt\&d)}$$

For this indicator, we considered that if the output is 0, the level of threats automatically will be the highest value of 1 since it cannot fulfill the developed standards or concepts from economic theory. In addition, when the output is lower than the minimum settled value in its correspondent standard or concept from the economic theory, it will be negative, and for the aforementioned reasons, it needs to be summed to 1, but it only applies if the output ranges between -0.99 and -0.01. Finally, if we have a case where the output from the relative indicator is a value higher than -1.0, it needs to be multiplied by -1.

It is required that the values obtained from the relative indicator fall into the margins of the mathematical constraint expressed in equation 2 of chapter 3. By performing these procedures, we are modifying and expanding the use of this scaling technique, in contrast with Gupta (2008), Gnansounou (2008), and Cabalu (2010), because in their cases, standards or concepts the economic theory were not employed. In this study, their use compensates for the negative outcomes resulting from the employment of standards and concepts from economic theory in weighting the single or aggregated measurement within its relative indicator. Furthermore, it helps in determining a more realistic threat level from the relative indicator.

Finally, for electricity transmission and distribution systems, we aimed to obtain data regarding frequency, voltage quality, system average interruption frequency index (SAIFI), and system average interruption duration index (SAIDI). However, not all our selected nations publish information regarding these indicators because their publication might discourage investment in the general economy when the performance of the systems is not the optimal to support productive industries. In addition, if the systems are deregulated and companies are publicly traded, data publication might discourage investments. However, we believe that data can be obtained and that our methodology can be implemented through consultancy in agreement with ministries of energy and mines, regulatory agencies, or congressional energy commissions interested in assessing the performance of their domestic industry in terms of supply security.

4.3 Model Integration

The simple and aggregated indicators can be tested into their respective relative indicators by following standards and concepts from the suggested economic theory. These criteria can provide robustness to our results. Our final goal is integrate a group of indexes for assessing supply security in the electricity industry's supply chain. We aimed at developing a new quantitative method for assessing energy security levels to contribute to the understanding of situations that decrease or improve the industry's performance (Aldana and Kim, 2013).

4.3.1 RSSSI's Integration

RSSSI is the output for the energy resource system supply security index for a given nation *j* during year *k*. It represents the system's security level and is obtained by employing equation 4. First, the set of single and relative indicators corresponding to the energy resource system were fitted into the respective relative indicators. The relative indicators need to operate into the margins of their corresponding technical standard or concept from economic theory. Finally, the output of each of the four relative indicators was squared, summed, divided by four, operated into the mean square, and finally deducted from one to obtain the system's security level. This index is integrated as follows:

$$\mathbf{RSSSI = 1 - \sqrt{\ ([(\chi R_{1\mathit{jk}})^2 + (\ \chi R_{2\mathit{jk}})^2 + (\ \chi R_{3\mathit{jk}})^2 + (\ \chi R_{4\mathit{jk}})^2] \div 4)}} \qquad \mathbf{(8)}$$

We define RSSSI as the output for the energy resource system supply security index for a given nation *j* during year *k*. χR1 accounts for the relative indicator for the reserves to production ratio (RPR), χR2 represents the relative indictor for the regional energy security index price (ESIprice_regional), χR3 embodies the relative indicator for energy resources imports dependency (ERID), and χR4 accounts for the relative indicator for energy mix diversification (EM).

4.3.2 GSSSI's Integration

GSSSI is the output for the electricity generation system supply security index for a given nation *j* during year *k*. It represents the system's security level. It is obtained through employing equation 5. First, the set of single and relative indicators corresponding to the energy resource system were fitted into the respective relative indicators. The relative indicators need to operate into the margins of their corresponding technical standard or concept from economic theory. Finally, the output of each of the four relative indicators was squared, summed, divided by four, operated into the mean square, and finally deducted from one to obtain the system's security level. This index is integrated as follows:

$$\mathbf{GSSSI = 1 - \sqrt{\,([(\chi G_{1jk})^2+(\chi G_{2jk})^2+(\chi G_{3jk})^2+(\chi G_{4jk})^2] \div 4)}} \qquad \mathbf{(9)}$$

We define GSSSI as the output for the electricity generation system supply security index for a given nation *j* during year *k*. χG1 accounts for the relative indicator for electricity import dependency (ERID), $\chi G2$ represents the relative indictor for the reserves capacity factor (RCF), $\chi G3$ embodies the relative indicator for effective installed capacities (EIC), and $\chi G4$ accounts for the relative indicator for infrastructure age factor (IAF).

4.3.3 TDSSSI's Integration

TDSSSI is the output for the electricity transmission and distribution systems supply security index for a given nation *j* during year *k*. It represents the system's security level. It is obtained through employing equation 6. First, the set of single and relative indicators corresponding to the energy resource system were fitted into the respective relative indicators. The relative indicators need to operate into the margins of their corresponding technical standard or concept from economic theory. Finally, the output of each of the four relative indicators was squared, summed, divided by four, operated into the mean square, and finally deducted from one to obtain the system's security level. This index is integrated as follows:

$$\mathbf{TDSSSI = 1 - \sqrt{\ ([(\chi T\&D_{1\mathit{jk}})^2 + (\chi T\&D_{2\mathit{jk}})^2 + (\chi T\&D_{3\mathit{jk}})^2 + (\chi T\&D_{4\mathit{jk}})^2] \div 4)} \quad (10)}$$

We define TDSSSI as the output for the electricity transmission and distribution system supply security index for a given nation *j* during year *k*. $\chi T\&D1$ accounts for the relative indicator for the utilization factor of transformers (UftT&D), $\chi T\&D2$ represents the relative indictor for the utilization factor of power lines (UFplT&D), χT&D3 embodies the relative indicator for the losses factor (LfT&D), and χT&D4 accounts for the relative indicator for the power factor (IAF).

4.3.4 EISSI's Integration

EISSI is the output for the electricity industry supply security index for a given nation *j* during year *k*. It represents the overall industry's supply security level. It is obtained through inputting the outputs of equations 8, 9, and 10 into equation 7. By these means, the set of composite supply security indexes corresponding to the energy resource system, the electricity generation system, and the electricity transmission and distribution systems was fitted into equation 7. Finally, the output of each of the composite supply security indexes was squared, summed, divided by three, and operated into the mean square to obtain the overall electricity industry's supply security level. This index is integrated as follows:

$$\mathbf{EISSI}=\sqrt{}\ ([(\chi \boldsymbol{RSSSI_{jk}^2})^2 + (\chi \boldsymbol{GSSSI_{jk}^2})^2 + (\chi \boldsymbol{TDSSSI_{jk}^2})^2] \qquad \mathbf{(11)}$$

RSSSI represents the output of the composite indicator for the energy resource system in terms of supply security. GSSSI represents the output of the composite indicator for the electricity generation system in terms of supply security. Finally, TDSSSI represents the output of the composite indicator for the electricity transmission and distribution system in terms of supply security.

We have fitted a set of simple and aggregated indicators into a set of relative indicators. Then, by following the principal component analysis[32] principles, the relative indicators were assessed with the use of technical standards as well as concepts from economic theory. Our developments can contribute to an understanding of situations that decrease or improve security levels, as demonstrated in the following Chapter. Finally, this model can be used in future analysis in other sub-sectors that compose the energy industry, as in the case of hydrocarbons or minerals. It is not limited to the selection and integration of more indicators. The minimum requirements will be to identify applicable indicators based on data availability regarding potential threats affecting performance and employing technical standards as well as concepts from economic theory that are applicable to each area of the supply chain. After combining all the indexes with the same model, a general supply security index can be achieved.

Our method is a more value-objective-oriented instrument than others. By these means, we are able to allocate more reasonable values to evaluate both efficiencies and inefficiencies in complying with standards in certain activities of a given system. Our choices were aimed to support our results. The designated measurements provided criteria about areas susceptible to risks that can be integrated to assess security levels in the different systems that compose the electricity industry's supply chain. The selection of indicators responds to available official statistical data regarding the performance achieved by the electricity industry from the countries under study during the period from 2000 to 2011.

[32] Khayyat and Lee (2010).

Chapter 5. Results Analysis and Discussion

The results are presented in the sections 5.1 and 5.2. The first section provides an explanation of our security indexes results by country and each of the systems that compose the electricity industry of the under studied nation. Finally, in section 5.2 the results were comprised and are being presented by systems and according the countries' topographies. In this regard, we have classified the under studied nations in two different sets, and each one is composed by six nations that respond to common geographical characteristics in terms of geological, social and economic conditions. The first set is defined as the large group of countries, which is composed by Mexico, Colombia, Ecuador, Peru, Chile, and Argentina. On the other hand, we have a small group of States, which is integrated by the Central American Republics (Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama).

5.1 Security indexes results by country

5.1.1 Mexico's electricity industry

5.1.1.1 Mexico's energy resources system

Mexico is a net exporter of hydrocarbons, without processing or transformation, which also has impacted negatively in reducing its proven reserves of fossil fuels. The country has not been able to accomplish new discoveries and additions during the period under study. During the past 12 years, the country became a net importer of natural gas. This nation has experienced price fluctuations in importing this energy commodity because its prices have been linked to oil prices. In addition, Mexico is highly dependent on the U.S., because it is the largest supplier. The risks increased as a consequence that the U.S. is susceptible of the political instability that characterized the Middle East countries, which are the main providers of crude oil and because of the relationship of this commodity with natural gas prices. Another limitation for Mexico is its energy mix for electricity generation, which is mostly concentrated on fossil fuels resources. Figure 5.1 shows Mexico's energy resources system security of supply performance.

Figure 5.1 Mexico's RSSSI

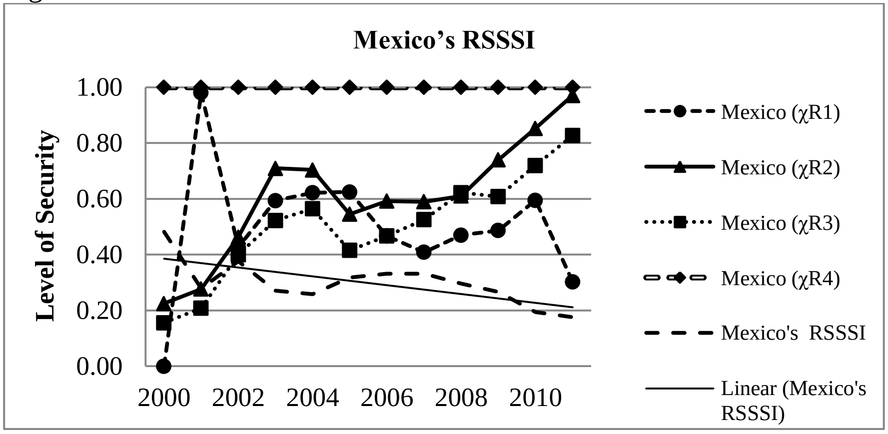


Figure 5.1 shows the performance of the indicators that compose Mexico's energy resources system security of supply index (RS). The observed behavior on the indicators χR2, χR3, and χR4 means that their values are in direction toward 1. This situation reflects a low performance in these indicators and jeopardizes the entire system. The nature of χR1 is more dynamic than the other indicators and it responds strictly to demand requirements, levels of production, and the accomplishment of new discoveries and additions of fossil fuels to the Mexico's stocks of proven

reserves. All these facts have affected the performance of the country's RS index because the level of performance decreased from 48% in the year 2000 to 18% in 2011. We considered that this variation during the period under study is high, it has been faster, and it's the most dramatic case on the energy resources system. The level of security of supply has decreased 30%, as a result of a 'chain effect'.

The path of Mexico's RS index is decreasing in a direction closer to 0 and it means low level of security of supply in the system. The main reasons have been export of domestic resources as well as demand increasing. These facts have produced the raise in the production levels of fossil fuels till decrease proven reserves and made of the country a net importer of natural gas from a larger and highly concentrated supplier, which is susceptible of price fluctuations. The instability of the prices of natural gas has also been affected. Additionally, as we have set before, Mexico is vastly dependent on fossil fuels resources in electricity generation. All the indicators that composed the RS index are interrelated and in this case all of them have been facing difficulties and that is how we understand the low performance in terms of security of supply for Mexico's energy resource system.

5.1.1.2 Mexico's electricity generation system

The Mexican electricity generation system is constituted as a vertical integrated monopolist with a limited private participation through the business model of independent power producers (IPPs). This is the only form of private participation in this system whereas the Comisión

Federal de Electricidad (CFE) is the large state owned enterprise in charge of the system. The electricity generation system has an installed power capacity at the year 2011 of 52.51 GW. Mexico’s power plants technologies 52.03% are based on gas, 16.19% crude oil commodities, 13.70% hydro power, 12.01% coal, 2.17% nuclear power, and 3.90% solar and wind power. The development of new power plants growth has registered an average annual growth of 3.62% during the period under study. Mexico is highly dependent on employing fossil fuels and thermal power plants to produce electricity.

The disadvantage of settling thermal power plants is that these types of equipment are limited to reach efficiencies over 60%. Domestic production of electricity at the year 2011 reached 257 TWh while consumption represented 201 TWh. For the foregoing reasons, the country is performing as a net exporter of electricity. The infrastructures’ ages as well as the core energy resources and technologies employed to produce electricity are the main factors affecting the overall performance of Mexico’s electricity generation system. The levels of effective capacities and reserves are attached to age of equipment as well as the preciseness of maintenances and upgradings. The country is involved in the development of new power plants as well as accomplishing upgradings and operations related to maintenances of equipment. Figure 5.2 shows Mexico’s electricity generation system security of supply performance.

Figure 5.2 Mexico’s GSSSI

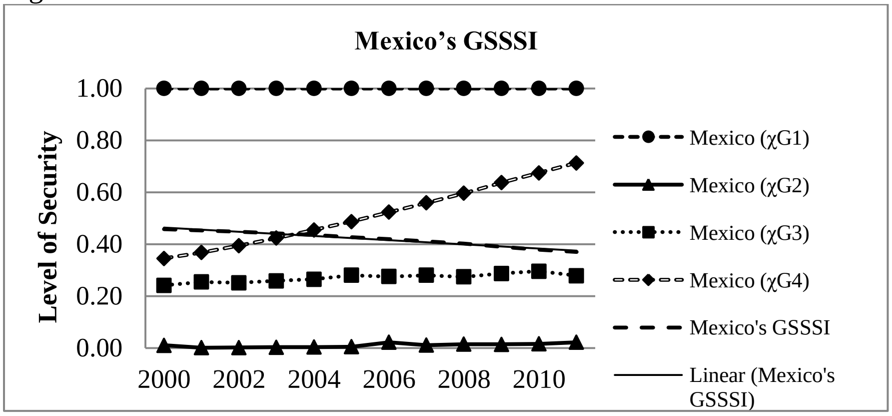


Figure 5.2 presents the performance of the indicators that compose Mexico’s electricity generation system security of supply index (GS). In one hand, the observed behavior of the indicators χG1 and χG4 means that they are closer to 1. This situation reflects a low performance of those indicators and exposes the entire system. On the other hand, the nature of χG2 and χG3 seems to be more conservative than the other indicators. It obeys to the facts that Mexico has been trying to expand its electricity generation system through accomplishing the development of new power plants as well as upgrading old thermoelectric units that have a low productive output (CFE, 2007-2012)[33]. Despite of the accomplished efforts, most of the country’s power plants have in average a medium level of efficiency and the equipment ages is another factor that is affecting the performance of the electricity generation system.

Although Mexico has been importing electricity, the traded volumes have not been significant, since the country has been able to

[33] As established by the National Development Plans (PND) for electrical infrastructure expansion (CFE, 2011).

respond demand requirements by itself and in some way the country has been self-sufficient in terms of electricity production. However, the performance of the country's GS index has decreased from 46% in the year 2000 to 37% in 2011, which is a medium low level of security. We considered that this variation during the period under study has been measured and it has been as a consequence of the nature of the generation infrastructure as well as its age. The behavior of Mexico's GS index is decreasing towards 0 and it means that the level of security of supply in the generation system is getting low. We believe that reducing the dependency from fossil fuels as well as selecting other type of technologies with high level of efficiencies to produce electricity can stimulate a positive impact on the level of security of the overall system.

5.1.1.3 Mexico's electricity T&D systems

The Mexican electricity transmission and distribution systems are owned and operated by the Comisión Federal de Electricidad (CFE), which is the state owned enterprise in charge of the whole electricity industry. In these systems, private participation has not been allowed yet and it remains as a pure state monopolistic model. The systems have an installed capacity at the year 2011 of 50,322 kilometers in power lines, while 155,920 MWA in transformer capacities. Infrastructure development has growth at 2.49% in average per annum, while electricity demand has growth at 2.39% in average per annum. The margins between infrastructure development and demand's growth do not allow the systems to count with enough reserves in transformers and it is operating far from the limits settled on technical standards.

The average number of interruptions annually per customer is around 3.25, while its duration is around 2.17 hours. Total electricity coverage in Mexico is 98.5% (2010), being 99.4% in urban areas and around 96.8% in rural ones. Electricity price are highly subsidized through fiscal resources and at the year 2011 it was in average US $ 0.115 per kWh. The main challenges for both systems are the development of a more robust infrastructure that responds to demand requirements on time as well as working under technical standards to improve efficiency and security of supply. Figure 5.3 shows Mexico's electricity transmission and distribution systems security of supply performance.

Figure 5.3 Mexico's TDSSSI

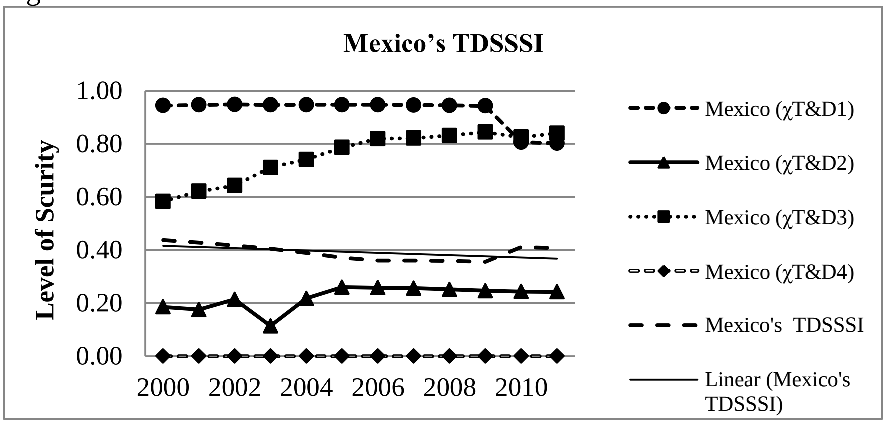


Figure 5.3 illustrates the performance of the indicators that compose Mexico's electricity transmission and distribution systems security of supply index (T&DS). The observed behavior on the indicators χT&D2 and χT&D3 is increasing. This situation reflects a decreasing

performance on those indicators and also risks the entire system because of infrastructure overexertion is carrying out heat over itself and it also increase the level of technical losses. Continue with our analysis we have that the nature of χT&D1 and χT&D4 is positive in comparison with the other two indicators. This situation follows the facts that Mexico has expanded the infrastructure of substations on its electricity transmission and distribution systems (CFE, 2007-2012)[34]. The accomplished improvements also have favored positively the performance of the power factor.

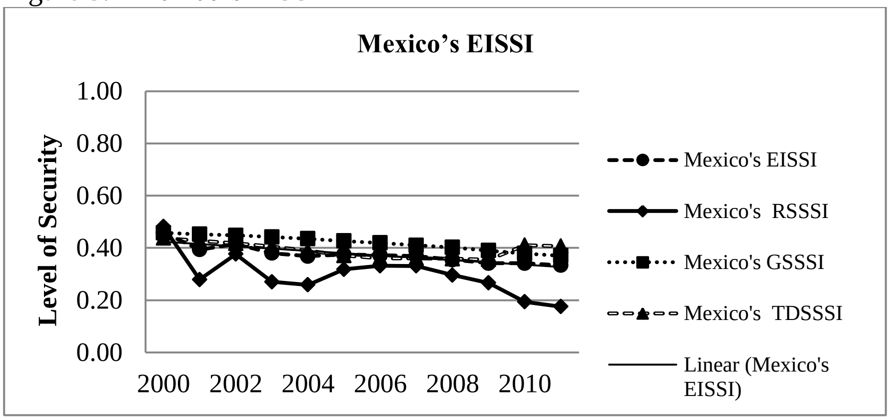
Mexico's T&DS index has decreased 3% for both systems during the period under study. The country's T&DS index retreated from 44% in the year 2000 to 41% in 2011, which is a medium level of security for the entire system. We considered that this variation has been slightly weaker in comparison with the behavior shown by the industry's upstream systems (energy resources and electricity generation), and as we have set before it is as a consequence of the expansion of the accomplished infrastructure. However, the reduction in Mexico's T&D index is as a result of demand increasing and because the entire electrical infrastructure that is required has not been developed yet, at the same rhythm than demand's growth. As a consideration, we have considered that these inefficiencies in the downstream systems (electricity transmission and distribution systems) enhancement are also inefficiencies on the upstream systems in order to compensate that 'losses'.

[34] As established by the National Development Plans (PND) for infrastructure expansion

5.1.1.4 Mexico’s electricity industry security of supply index

Mexico’s EISSI has shown that the performance of the industry is strictly attached to the resource system outcomes as well as to the infrastructure efficiency. The country’s electricity industry has a low high level of security due to its volatile performance in the energy resources as well as in the electricity generation system. In addition the electricity transmission and distribution systems have decreased its level of security of supply. The reduction in the performance of all the systems is the main cause of Mexico’s EISSI low output. The theory sets that both energy resources as well as electrical infrastructure have a nominal installed capacity which cannot be exceeded if there are not new additions of infrastructure or technological improvements. This constraint is due to the fact that productive facilities by nature are subjected to their nominal installed capacity and consecutively with their production frontier. Figure 5.4 shows Mexico’s electricity industry security of supply performance.

Figure 5.4 Mexico’s EISSI



Based on the analysis of Figure 5.4 we can set that Mexico's EISSI has decreased from 46% in the year 2000 to 33% in 2011. We have seen that security level has decreased in a constant way since it reduces 13% during the period under study. As a matter of fact, the main causes in decreasing Mexico's EISSI have been the energy resource depletion and exports, as well as electricity demand's growth. This last factor also has boosted infrastructure overexertion in all the systems. Mexico's electricity generation facilities by the nature of the employed technologies in electricity production have a low level of efficiency, which limits the performance of the electricity generation system. Additionally, the industry has not been effective in increasing electrical infrastructure capacities as well as diversifying its energy mix for producing electricity. The developments of new electrical infrastructure have not been at the same rhythm as the demand's growth.

Mexico's electricity industry has been affected by a 'chain effect' in which the downstream systems, which are closer of the demand and are susceptible of its effects, advance the upstream systems in order to compensate their inefficiencies. The implications for this country in order to achieve security of supply in its electricity industry should start by diversifying and selecting less risky energy resources suppliers as well as employing more renewable energy resources in order to minimize risks and through controlled price's fluctuation. The country needs to implement technologies for electricity production that do not only provide more installed capacities and reserves levels, but also operate at higher levels of efficiency. The electricity transmission and distribution infrastructure need to be robust by means of automation and increase power lines coverage.

These actions are required in order to mitigate congestion and overexertion problems, and it can be through building parallel lines, increasing voltage levels or developing distributed generation systems closer to demand. Finally, the national electricity industry needs to operate under well recognized standards in order to keep an optimal level of security of supply.

5.1.2 Guatemala's electricity industry

5.1.2.1 Guatemala's energy resources system

Guatemala owns hydrocarbons but the nation does not have an appropriate infrastructure for refining them in order to be used for its own benefit and transform the fossil fuels that are produced domestically. The nation is a net exporter of crude oil and this fact has contributed in reducing its proven reserves over the time. The nation is dependent on imports of processed fuels to produce electricity and the prices of those commodities have been susceptible of fluctuations due to the shocks on the international markets. The country has been trying to minimize the volume of energy commodities that are imported for producing electricity as well as diversifying its number of suppliers in order to mitigate risks. In addition, Guatemala is trying to exploit other type of domestic resources to produce electricity and with this action reducing the concentration ratio in employing fossil fuels for producing electricity. Figure 5.5 shows the performance of Guatemala's energy resources system, which has evolved positively during the period under study.

Figure 5.5 Guatemala’s RSSSI

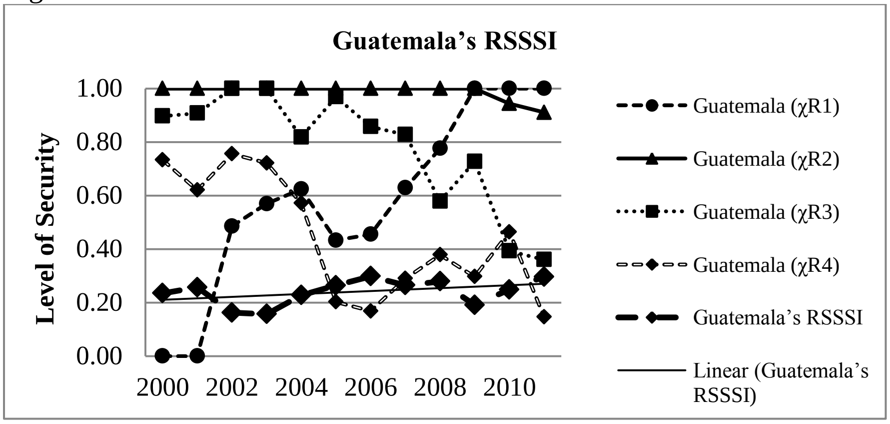


Figure 5.5 shows the performance of the indicators that compose Guatemala’s energy resources system security of supply index (RS). As we have seen χR1’s behavior shows that it has reached the maximum level of insecurity or risk because the country’s reserves for hydrocarbons have been reduced to its minimum level during the period under study. The indicator χR2 although is still closer to 1 has shown a decreasing conduct and it means improvements in its level of security. This situation submits to the fact that Guatemala has also reduced its dependency regarding imports of fossil fuels for producing electricity and has started to diversify the number of suppliers in order to mitigate negative effects due to price fluctuations. The positive effect shown by this indicator is as a result of the improvement on security levels in both indicators χR3 and χR4. Guatemala has been doing efforts in order to change the nation’s energy mix for producing electricity based mostly on renewable energy resources which are abundant in its national territory.

The performance of Guatemala's RS index is increasing in a direction different than 0 and it means improvement in the level of security of supply in the energy resources system. The index has improved from 23% in the year 2000 to 30% in 2011.The main reasons have been the adopted policies and implementation of these policies by policy makers in order to reduce the country's dependency on fossil fuels imports and its employment in electricity generation. Also, this nation has started to diversify the number of suppliers in order to mitigate negative effects due to price fluctuations on oil's international markets. The country improved its RS index in a measurable way despite the fact that the indicator has been affected by its dependency on export domestic fossil fuel resources which was a reason to decrease proven reserves. All the indicators that compose the RS index are interrelated and in the case of this country most of them have been increasing its performance in terms of security of supply for Guatemala's energy resource system, which has been positive.

5.1.2.2 Guatemala's electricity generation system

Guatemala's electricity generation system was unbundled in order to promote competitiveness through private participation. After deregulation the system's infrastructure growth, around INDE and currently 48 different private participants, reached 80% of the installed capacities, while government owns just 20%. Although government has decreased its participation in the system it still has large participation in electricity production because its core technologies are hydro power plants which operate permanently as base plants. INDE has market participation in the power market for around 32%. The electricity generation system has an installed power capacity at the year 2011 of 2.45 GW. Guatemala's power plants technologies are based 37% on hydro power, 30% thermal power through biomasses, 19% thermal power through crude oil commodities, and 14% thermal power through coal.

The development of new power plants growth has registered an average annual growth of 3.87% during the period under study. The country depends 63% on thermal power and 37% on hydro power. Domestic production of electricity at the year 2011 reached 8.15 TWh while consumption represented 8.68 TWh, and for these reasons the country is performing as a net importer of electricity because its electricity industry imported 0.53 TWh either from Central America or Mexico. Guatemala's target is to develop new hydro power plants in order to improve its energy mix and make the best use of its domestic available resources. The infrastructure efficiency as well as natural phenomena is the main factors affecting the overall performance of this system. Figure 5.6 shows the performance of Guatemala's electricity generation system.

Figure 5.6 Guatemala's GSSSI

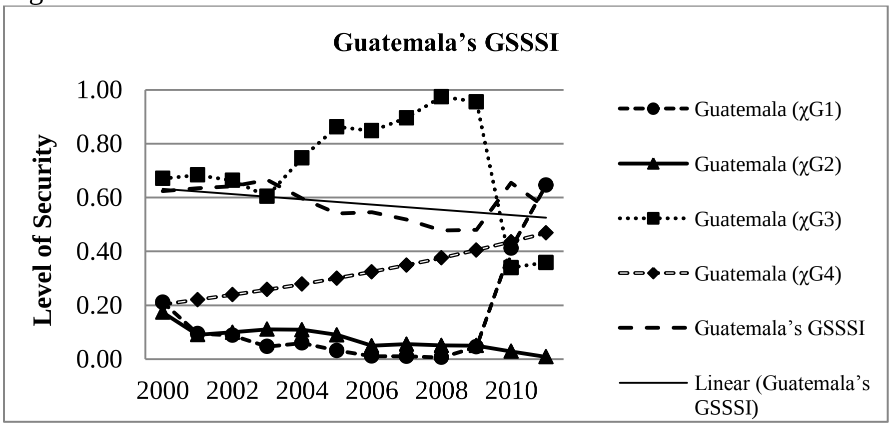


Figure 5.6 illustrates the performance of the indicators that integrate the country's electricity generation system security of supply index (GS). In one hand, the observed behavior of the indicators $\chi G1$ and $\chi G4$ is decreasing its performance and its level of security since growing in direction to 1. Both indicators are decreasing security in an exponential way since they are performing out of the established parameters. As a matter of fact the effective installed capacities in power plants, mainly based on thermoelectric technologies are not working at their nominal installed capacities. Besides, that infrastructure is getting older and upgradings as well as the development of new projects will be required during the future years.

On the other hand, $\chi G2$ and $\chi G3$ have shown a positive outcome in reducing electricity imports and increasing the levels of reserves in the electricity generation system. These positive aspects can be as an outcome of the reduction of technical losses in the electricity transmission and distribution systems or by means of developing new power plants that are offering their capacities as reserves since they do not have a power purchase agreement (PPA) contract.

Among the different systems that compose the Guatemalan electricity industry is the one that shows a reduction in the output of security of supply. Guatemala's GS index is under a medium range level of security. The performance of the index decreased 6% during the period under study since it moved from 62% in the year 2000 to 56% in 2011. As we have set before what seems to be a threat for Guatemala's electricity generation infrastructure are the power plants' eras. This situation was mainly noticed for large hydropower plants as well as thermoelectric equipment with more than 20 years and which are finishing their lifespan. The country is involved in developing new energy power projects or accomplishes the required upgrading (CNEE, 2008, 2012, 2013)[35]. However, there is social resistance as well as negative environmental effects that diminish the probability to develop more hydro power plants.

5.1.2.3 Guatemala's electricity T&D systems

Guatemala's electricity transmission and distribution systems are owned by private and governmental entities. However, INDE still owns more than 75% of the existent infrastructure. It is expected that this situation change by the year 2018 when several rings with a voltage superior to 138 kV will be accomplished by a private consortium. Horizontal unbundling has been enforced by levels of voltages with the objective for improving infrastructure efficiencies. The systems have an installed capacity at the year 2011 of 3,937 kilometers in power lines, while 1,531 MWA in transformer capacities. Infrastructure development has growth at 3.01% in average per annum, whereas electricity demand has growth at 4.82% in average per annum. The margins between infrastructure development and demand's growth do not allow the systems to count with enough reserves and operate out of technical limits built on standards.

[35] Guatemala's electricity generation expansion plans 2008-2018, 2012-2022, 2013-2027

Total electricity coverage in 2011 was 85.1%, almost 94% being in urban areas and around 70% in rural ones. The average number of interruptions annually per customer in urban areas was around 3, while its duration was around 8.43 minutes. Although electricity prices are settled under market mechanisms in the electricity generation system, these prices have been the most expensive in the American continent because they were in average US $ 0.249 per kWh in 2011. The government through INDE provides subsidies for the customers below 100 kWh of monthly consumption. The main challenges for both systems are the development of a more robust infrastructure that responds to demand requirements on time as well as works under technical standards to improve efficiency and security of supply. Figure 5.7 presents Guatemala's electricity transmission and distribution systems security of supply performance.

Figure 5.7 Guatemala's TDSSSI

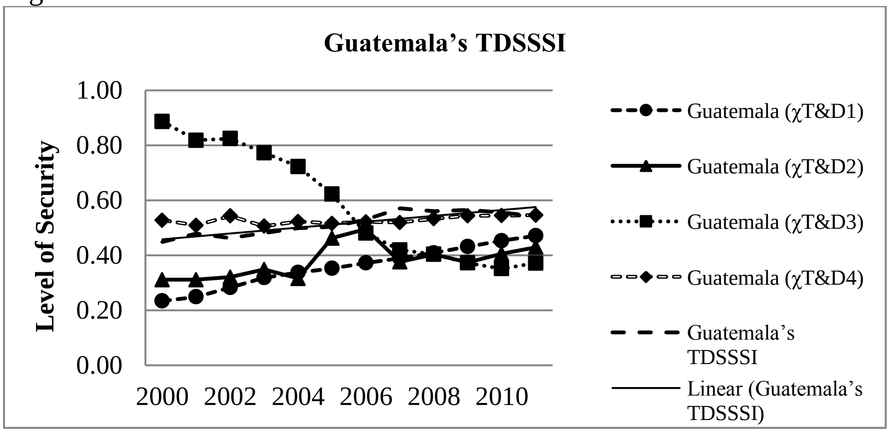


Figure 5.7 shows the performance of the indicators that compose Guatemala's electricity transmission and distribution systems security of supply index (T&DS). The noticed behavior of the indicators χT&D1,

χT&D2 and χT&D4 is decreasing softly its security level over the time as a result of the fact that electricity demand's growth is faster than the development of new electrical infrastructure associated with transformers and power lines. These facts have affected existent equipment since they have been overused and have affected the power factor. In spite of these negative situations, the country has undertaken efforts in order to mitigate losses by means of accomplishing automation of substations and improving remote communications with the implementation of optical fiber on power grids as part of the Central American electrical interconnection (SIEPAC). It seems that automation plays a significant role in keeping or increasing the level of security of supply in the overall systems because of the technical losses which are represented by the indicator χT&D3 have shown a positive and fast performance.

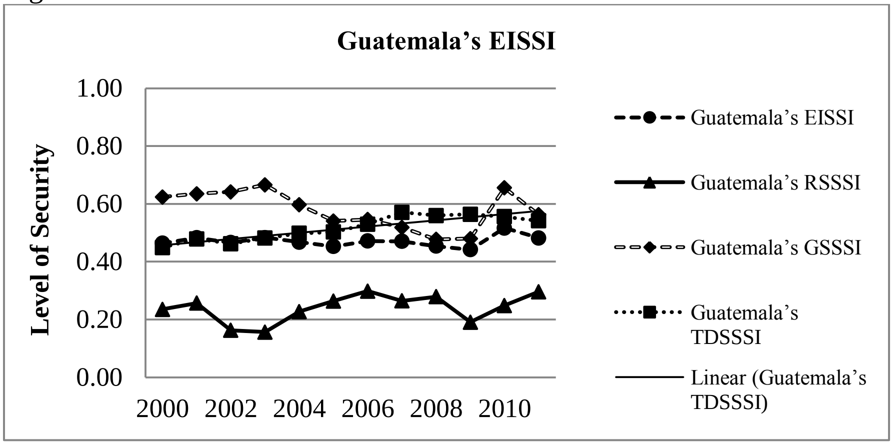
Guatemala's T&DS index has increased 9% for both systems during the period under study. The country's T&DS index moved positively from 45% in the year 2000 to 54% in 2011, which is a medium level of security for the entire system. We considered that this variation has been reasonable despite the negative performance of infrastructure utilization and the power factor of the systems. The implication of the results is the fact that automation is playing a vital role in reducing technical losses although infrastructure overexertion. We considered that the country is doing an optimal use of its electrical infrastructure in these systems. Furthermore, the efficiencies in the downstream systems (electricity transmission and distribution systems) are enhancing efficiencies of the upstream systems in order to compensate that 'losses'.

We can support our argument based on the fact that in electricity generation system was observed a positive outcome for reserve capacities.

5.1.2.4 Guatemala's electricity industry security of supply index

Guatemala has a medium level of security of supply in its electricity industry due to the accomplished improvements in the energy resources system as well as in the electricity transmission and distribution systems. These systems are the main causes for the enhancement in the output of Guatemala's EISSI since they have shown a positive growth over the time. Guatemala's EISSI increased, although quietly, from 46% in the year 2000 to 48% in 2011. For both energy resources as well as electrical infrastructure the country undertook policies in order to mitigate existent risks as well as add new infrastructure. Policy makers have been trying to respond with actions to the demand requirements as well as the constraint of productive facilities by upgrading existent equipment. Figure 5.8 shows Guatemala's electricity industry security of supply performance.

Figure 5.8 Guatemala's EISSI



Based in our findings and the patterns observed in Figure 5.8 we can set that the improvements in security of supply in the Guatemalan electricity industry follows the reduction in the volume of energy commodities that are imported for producing electricity as well as diversifying the number of suppliers. The country is trying to exploit other type of domestic renewable energy resources to produce electricity and with this action reducing the concentration ratio in employing fossil fuels in electricity generation. The trend in electricity imports dependency is to reduce since new power plants have been developed in order to improve capacities as well as respond to demand requirements. The accomplishments in electricity transmission and distribution systems also have favored efficiency and the increase of security of supply in the industry's upstream systems (energy resources and electricity generation systems).

Additionally, Guatemala is trying to accomplish for the year 2018 the upgrading of its electricity transmission system. The main activities to be undertaken are increasing voltage levels, development of electricity transmission rings, and automation of the entire infrastructure in both systems (CNEE, 2008). However, Guatemala's energy resource and electricity generation systems are vulnerable to environmental negative impacts because of the natural phenomena of El Niño and La Niña. In this regard policy makers for the development of future power plants need to consider the adoption of coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment.

These actions are in order to stimulate a positive impact in the level of security of the overall energy resource system as well as electricity generation system. By these means, the nation can access other kinds of energy resources as well as increase power generation capacities in order to mitigate risks due to the concentration of activities. These actions can also be oriented to support the development of distributed generation systems. In summary, all the indicators are expected to improve their performance as well as the level of security in general for the national electricity industry.

5.1.3 El Salvador electricity industry

5.1.3.1 El Salvador energy resources system

El Salvador is a nation which lacks fossil fuel resources because of geological matters. Also, in this study it is the smallest nation in our study in terms of territorial extension. With the exception of Guatemala and Belize (this country was not considered in our study), are the only two countries in the Central American region which own, produce and export hydrocarbons. According to ECLAC (2012) El Salvador one of the two countries in the America's Continent with low production levels of hydro resources because of geographic, demographic, and environmental issues. These situations limited El Salvador in being self-sufficient owning enough energy resources to produce hydroelectricity. Although the lack of energy resources the country has applied accurate policies in order to make the better use of its available resources as the case of geothermal power, which has contributing in diversifying the nation's energy mix to produce electricity. Figure 5.9 shows El Salvador energy resources system security of supply performance.

Figure 5.9 El Salvador RSSSI

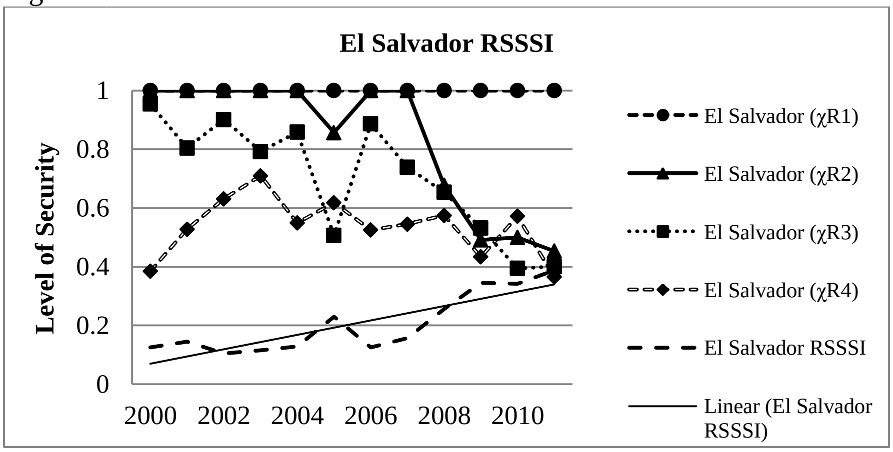


Figure 5.9 shows the performance of the indicators that compose El Salvador energy resources system security of supply index (RS). El Salvador lacks energy resource and for the mentioned reasons the performance of χR1 cannot be easily improved. Although this nation is a net importer of energy resources, its policy makers have minimized risks and controlled price's fluctuation through diversifying and selecting less

risky energy resources suppliers as well as employing more renewable energy resources in the nation's energy mix. This country is employing mainly hydro and geothermal resources for producing electricity although there is a sort of dependency on fossil fuels.

We can see in Figure 5.9 that the performance of the indicators χR2, χR3 and χR4 has improved positively in terms of security of supply over the time. Contrasted with Mexico, which is a rich country owning energy resources and with large territorial extension, El Salvador by employing positively these three policies has improved positively the performance of its energy resources system in terms of security of supply.

During the period under study, where price fluctuations in fossil fuels have been presented every day in the international markets, the performance of El Salvador energy resource system index (GS) has increased its level of security of supply from 13% in the year 2000 to 39% in 2011 as it was seen in the figure above. We considered that this variation during the period under study has been high and fast. Furthermore, this dramatic variation has been as a consequence of positive 'chain effect' due to policy decisions in selecting less risky energy resources suppliers as well as employing more renewable energy resources in the nation's energy mix. This can be a positive example to follow by other nations who lack energy resources and with similar geographical, demographic, and environmental conditions such as the case of El Salvador. However, renewable energy resources are instable by their own nature and it may affect the performance of electricity generation system by making the country a net importer of electricity from neighboring nations.

5.1.3.2 El Salvador electricity generation system

El Salvador electricity generation system was unbundled in order to promote competitiveness through private participation. After deregulation the system's infrastructure growth around the infrastructure of the Comisión Hydroeléctrica del Río Lempa (CEL) which was the largest SOE before liberalization. The strategy is the same as the one employed in the Guatemalan case. Currently there are 17 different private participants which own 77.73% of the installed capacities, while government owns just 22.27%. Although government has decreased its participation in the system, it still has large participation in electricity production because its core technologies are hydro power plants which operate permanently as base plants. CEL has market participation in the power market for around 34.52%. Installed power capacity at the year 2011 was around 1.50 GW.

The development of new power plants has registered an average annual growth of 2.84% during the period under study. At the year 2011 El Salvador was 65% dependent on thermal power and 35% on hydro power. Domestic production of electricity reached 5.73 TWh while consumption represented 5.97 TWh, and for the foregoing reasons, the country is performing as a net importer of electricity because its electricity industry imported 0.22 TWh from Central American neighboring countries. For El Salvador it is a challenge to develop more power plants based on renewable energy resources because the country is limited in territorial extension as well as hydro energy resources. The infrastructure efficiency as well as natural phenomena is the main factors affecting the overall performance of the system. Figure 5.10 shows El Salvador electricity generation system security of supply performance.

Figure 5.10 El Salvador GSSSI

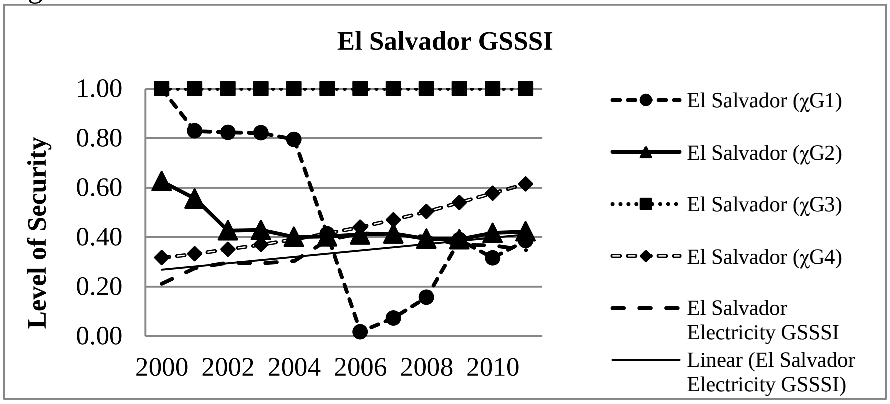


Figure 5.10 shows that although the tendency for the indicators χG1 and χG2 has been increasing in recent years both of them are still between an acceptable parameter of security of supply. The risks are represented for values closer to 1 and that is not the situation of these indicators at the end of the year 2011. As we have set before the positive outcomes from the performance of χG1 and χG2 have been that El Salvador electricity industry added more installed capacities and reduced its electricity imports dependency.

However, that has not been the case of the indicators χG3 and χG4 because the country has not been able to provide enough reserves capacities and these also have been affected by the power plants' ages. These situations have made El Salvador's electricity industry not to be self-sufficient producing electricity on the domestic level and the nation has to remain as a net importer of electricity from neighboring countries.

The performance of El Salvador electricity generation system has shown an acceptable improvement of 14% during the period under study since the level of security of supply moved from 21% in the year 2000 to 35% in 2011. The main cause of this accomplishment was the additions on installed capacities, which reduces high levels of electricity imports dependency. Based on the fact that El Salvador is involved in developing new power plants (SIGET, 2012)[36], we also have considered the country's geographical and environmental contexts.

These situations are in order to provide an opinion that the best option for improving the level of security of supply on the overall electricity generation system is through the development of power plants based on coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment. These actions also may carry out the country to be self-sufficient producing electricity, offer enough reserves capacities and become in a net exporter of electricity policy makers most.

5.1.3.3 El Salvador electricity T&D systems

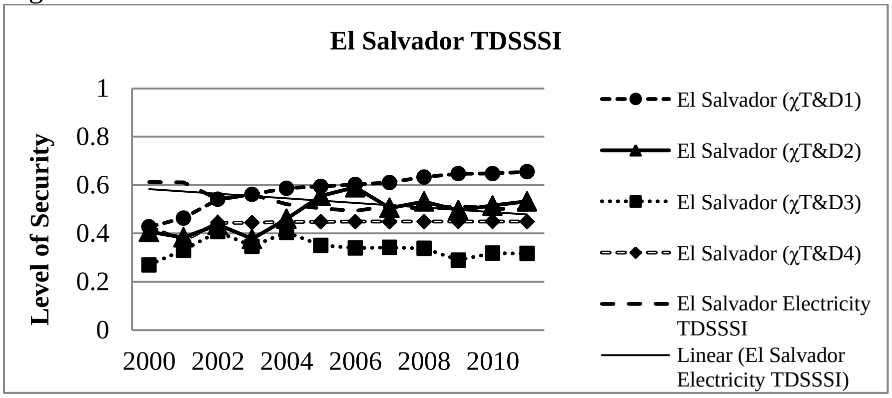
El Salvador electricity transmission and distribution systems are owned and operated by both State and private sector. Electricity transmission is operates by the governmental state owned enterprise, Empresa Transmisora de El Salvador (ETESAL), while electricity distribution is unbundled into 5 companies which are owned and operated by private consortiums. The distribution companies were unbundled

[36] El Salvador generation expansion plan 2012

geographically. The systems have an installed capacity at the year 2011 of 1,180 kilometers in power lines, while 2,387 MWA in transformer capacities. Infrastructure development has growth at 4.19% in average per annum, while electricity demand has growth at 4.14% in average per annum. The margins between infrastructure development and demand's growth do not allow the systems to count with enough reserves and operate out of technical limits built on standards.

Total electricity coverage in El Salvador at the year 2011 was 85.4%, being almost 97% in urban areas and around 72% in the rural communities. The average number of interruptions annually per customer in urban areas was 12, while its duration was around 8.75 minutes. Electricity price is settled under market mechanisms in the electricity generation system and it was in average US $ 0.198 per kWh. The main challenges for both systems are the development of a more robust infrastructure that responds to demand requirements on time as well as working under technical standards to improve efficiency and security of supply. Figure 5.11 shows El Salvador electricity transmission and distribution systems security of supply performance.

Figure 5.11 El Salvador TDSSSI



The Figure 5.11 shows that El Salvador electricity transmission and distribution systems security of supply index (T&DS) has decreased over the time. The indicators χT&D1, χT&D2, χT&D3, and χT&D4 have decreased softly their performance. The track denotes that electricity demand growth has been the main cause in reducing the systems performance. As we have seen most of the problems regarding security of supply are located in the electricity distribution system since the country has a robust infrastructure in its electricity transmission system.

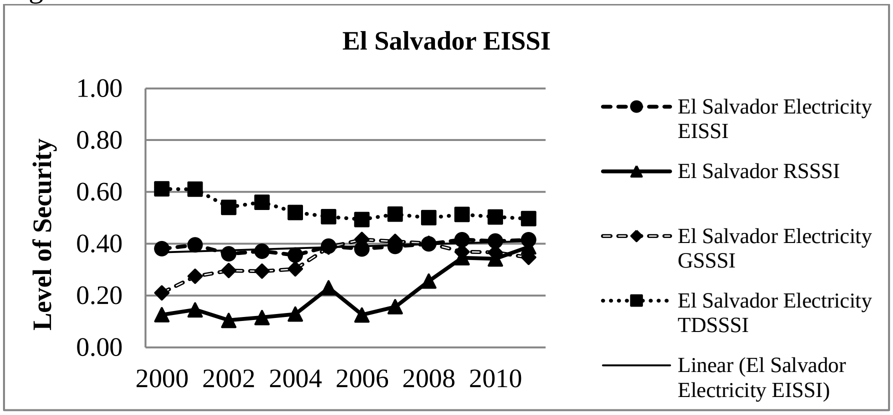
The overexertion of electrical infrastructure has carried out heat over itself and increase of technical losses as well as the reduction of the power factor performance in accordance with standards. The technical losses as well as the power factor negative effects have been stabilized due to the accomplishment of automation of substations as well as installing optical fiber on the electricity transmission system as part of the Central American electrical interconnection (SIEPAC).

For both systems security has decreased security during the period under study for around 11%, and it has been as a consequence of infrastructure overexertion, production of heat in the electrical infrastructure, and increased technical losses. Security of supply has decreased from 61% in 2000 to 50% in 2011. For the electricity distribution system equipment installed capacities have not been growing at the same level as demand's requirements. What is important to consider is the fact that inefficiencies in the downstream systems have been enhancing inefficiencies in the upstream systems in order to compensate mainly that technical losses. As a matter of fact, we have seen that the relationships exist since the reserves capacities levels were the indicator with lower performance and it also has motivated to continue importing electricity. These issues have affected negatively security in the electricity generation system.

5.1.3.4 El Salvador electricity industry security of supply index

The improvements in security of supply in El Salvador electricity industry responds to policy decisions that have carried out the diversification and the selection of less risky energy resources suppliers as well as employing more renewable energy resources in the nation's energy mix to produce electricity. The industry has been taking advantage of the country's available renewable energy resources to produce electricity based on its geothermal power potential. It has been minimized the use of fossil fuels in electricity generation. The trend in electricity imports dependency is to reduce since new power plants have been developed in order to improve capacities as well as respond to demand's requirements. Additionally, in order to reduce levels of technical losses in the electricity transmission and distribution systems automation of substations and implementation of optical fiber for the grids have been accomplished as part of the Central American electrical interconnection (SIEPAC). Figure 5.12 shows El Salvador electricity industry security of supply performance.

Figure 5.12 El Salvador EISSI



According to Figure 5.12 El Salvador has a medium low level of security of supply in its electricity industry due to the accomplished improvements in the energy resources system, electricity generation system, and electricity transmission system. These systems are the main causes for the enhancement in the output of El Salvador EISSI since they have shown a positive growth over the time. El Salvador EISSI increased, although softly, from 38% in the year 2000 to 42% in 2011. For both energy resources as well as electrical infrastructure the country undertook policies in order to mitigate existent risks as well as adding electrical infrastructures in both the electricity generation and electricity transmission systems. Policy makers have minimized risks and controlled price's fluctuation through diversifying and selecting less risky energy resources suppliers as well as employing more renewable energy resources in the nation's energy mix.

The case of El Salvador in terms of improving energy security in the energy resources system is one the positive examples that we have found and it can be a reference to follow by nations that lack enough energy resources to produce electricity domestically, and share similar geographical, demographic, and environmental conditions. However, renewable energy resources are instable by their own nature and it may affect the performance of electricity generation system by doing of the country a net importer of electricity from neighboring nations. The implications of the obtained results from El Salvador are that policy makers need to consider for the development of future power plants the adoption of coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment. These actions are in order to stimulate a positive impact in the level of security of the overall energy resource system as well as electricity generation system.

5.1.4 Honduras electricity industry

5.1.4.1 Honduras energy resources system

Honduras is a nation lacking fossil fuel resources because of its own geological nature, but the country has a considerable potential to produce electricity and be self-sufficient based on hydro energy as well as through biomasses. Despite this wealth of renewable energy resources, the nation has not been able to modify its energy mix from fossil fuels to renewables. This country has increased the employment of hydrocarbons from 38% in the year 2000 to 54% in 2011.

In other words, the country became a net importer and highly dependent on fossil fuel resources to produce electricity over the time. This nation has experienced price fluctuations in importing fossil fuels because its prices have been linked to crude oil prices in the international markets. In addition, Honduras has been highly dependent either on Venezuela or the U.S. as the largest suppliers and in any of the cases both nations have been highly concentrated. Figure 5.13 shows Honduras energy resources system security of supply performance.

Figure 5.13 Honduras RSSSI

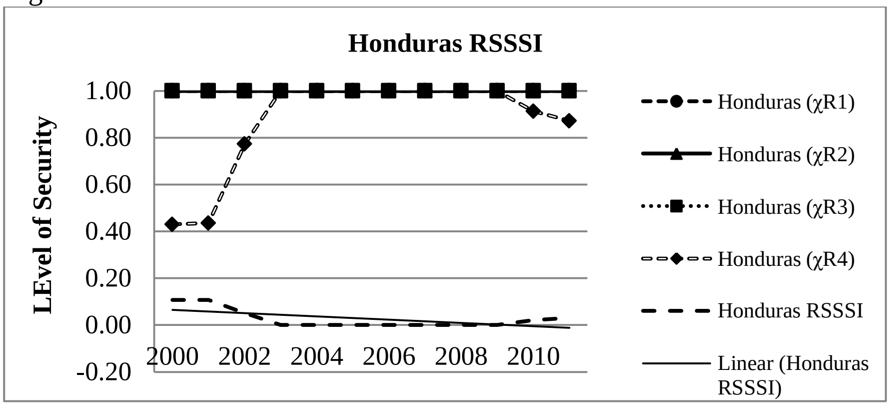


Figure 5.13 shows the performance of the indicators that compose Honduras energy resources system security of supply index (RS). The observed behavior of the indicators χR1, χR2, χR3, and χR4 is that all of them are either over 1 or closer to this value. These situations reflect a low performance of those indicators and a low level of security for the entire

energy system. As we set before it is because the country does not own and produce fossil fuels for its own consumption. Based on the energy mix to produce electricity the country is a net importer and highly dependent on fossil fuels. The risks on price fluctuations are present since the country has been high dependent and concentrated on one single supplier over the time. The country's RS index has decreased from 11% in the year 2000 to 3% in 2011, which is a very low level of security for the system. Although this variation during the period under study has been moderated the system has reached the maximum level of insecurity.

The path of Honduras RS index is improving in a direction separate from 0 and it means that some positive initiatives have been undertaken during the last years in order to improve security of supply in the energy resources system. It seems that changing the country's energy mix to produce electricity based on renewable as well as coal energy resources can be the solution to decrease concentrated dependency on fossil fuel imports, price fluctuations and decrease risks of depending on one single supplier.

This measure seems similar as the ones implemented by El Salvador but for Honduras still is not carried out an acceptable growth in the security level for the overall system. Honduras policy makers can also address the development of future power plants based on coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment. By these means, the nation can access other kinds of energy resources as well as increase power generation capacities.

5.1.4.2 Honduras electricity generation system

Honduras electricity generation system has large participation of independent power producers. The system is under the control of the state owned enterprise, Empresa Nacional de Energía Eléctrica (ENEE). Currently there are 39 private power plants which own 65.97% of the installed capacities, while government owns just 34.03%. The State utility has a market share of 34.97% because it operates permanently 7 hydro power plants. ENEE also it has 6 minor thermal power plants, which operate with crude oil commodities. The country's Installed power capacity at the year 2011 was around 1.78 GW. The development of new power plants growth has registered an average annual growth of 6.47% during the period under study. Also, at the same period of time this nation registered a 54% dependency in thermal power from oil commodities, 44% in hydroelectricity, while 2% in thermal power from biomasses. Domestic production of electricity at the year 2011 reached 7.17 TWh while consumption represented 5.28 TWh.

The differences between domestic production and consumption do not mean that the country is a net exporter of electricity. As a matter of fact, this nation is playing both functions in order to meet demand's requirements. The electricity industry depends on exports and imports from the Central American electricity market. However, the difference is still high and it follows high level of technical and non-technical losses in the electricity transmission and distribution systems. The challenges for Honduras electricity generation system are to develop future power plants based on renewable energy resources and own technologies in order to reduce its high dependency on fossil fuels, taking into consideration that it is required to select technologies with high levels of operational efficiency in order to meet the standards. The system's performance tends to be affected by the infrastructure's inefficiencies as well as negative environmental issues, which are a common characteristic of the entire region. Figure 5.14 shows Honduras electricity generation system security of supply performance.

Figure 5.14 Honduras GSSSI

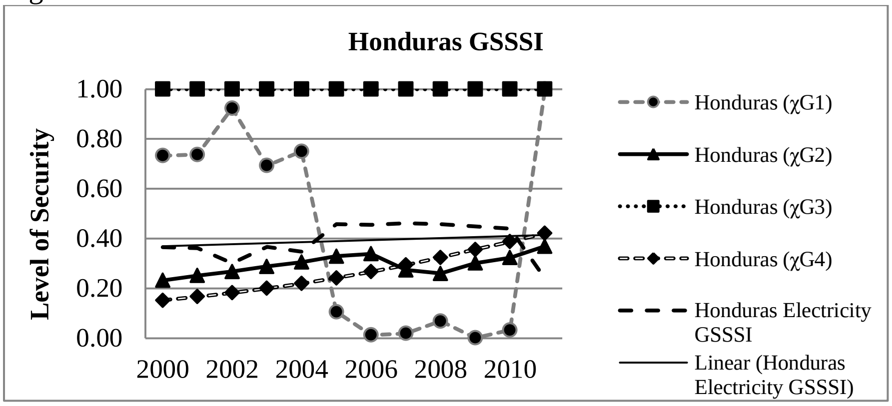


Figure 5.14 shows the performance of the indicators that compose Honduras electricity generation system security of supply index (GS). The observed behavior of the indicators χG1, χG2, χG3, and χG4 is that all of them are either over 1 or in way towards this value. This situation reflects a low performance of those indicators and a low level of security of electricity supply for the entire system. The performance of χG1 and χG3 is attached to the fact that in the Honduran electricity generation system most of the core technologies to produce electricity are based on thermal power plants. The power plants cannot reach optimal levels of nominal

installed capacities and keep appropriate levels of reserves. In addition, if maintenances are not being accomplished on time that will also affect capacities, demanding imports of more fossil fuel energy sources to produce electricity as well as electricity imports as it is reflected by χG2. The level of efficiency of power plants is also affected by the equipment age χG4 which is increasing steadily.

If new additions of installed capacities are not accomplished in the coming years the country may not be able to counter demand's requirements by itself or increase its dependency on electricity imports. The performance of Honduras GS index has decreased from 36% in the year 2000 to 24% in 2011. The index is decreasing towards 0 and it means that the level of security of supply on the generation system is getting lower. We considered that this variation during the period under study has been measured and it has been as a consequence of the own nature of the generation infrastructure as well as its age.

We believe that reducing the dependency from fossil fuels as well as selecting other type of technologies with high level of efficiencies to produce electricity can stimulate a positive impact on the level of security of the overall system. Policy makers can think in addressing the development of future power plants based on coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment.

5.1.4.3 Honduras electricity T&D systems

Honduras electricity transmission and distribution systems are owned and operated by Empresa Nacional de Energía Eléctrica (ENEE), which is the state owned enterprise in charge of the electricity industry. In these systems private participation has not been allowed yet and it remains as a pure state monopolistic model. There is no information regarding the installed capacity for both systems and it may obey to government policies not to publish this kind of information for security reasons. For the foregoing reasons, it was impossible to estimate the growth rate of electrical infrastructure in these systems and compare the margins between infrastructure development and demand’s growth. We believe that Honduras electricity industry is operating out of the parameters settled by technical standards.

In recent years the level of technical and non-technical losses has been placed in a range between 13% and 15%. Total electricity coverage in 2011 was 79.2%, being 97.7% in urban areas and around 60.5% in rural ones. During the same year, the average number of interruptions annually per customer in urban areas was 1.82 hours. In addition, electricity prices are subsidized through fiscal resources which represented in average US $ 0.183 per kWh. The main challenges for both systems are the development of a more robust infrastructure that responds to demand’s requirements on time as well as working under technical standards to improve efficiency and security of supply. Figure 5.15 presents Honduras electricity transmission and distribution systems security of supply performance.

Figure 5.15 Honduras TDSSSI

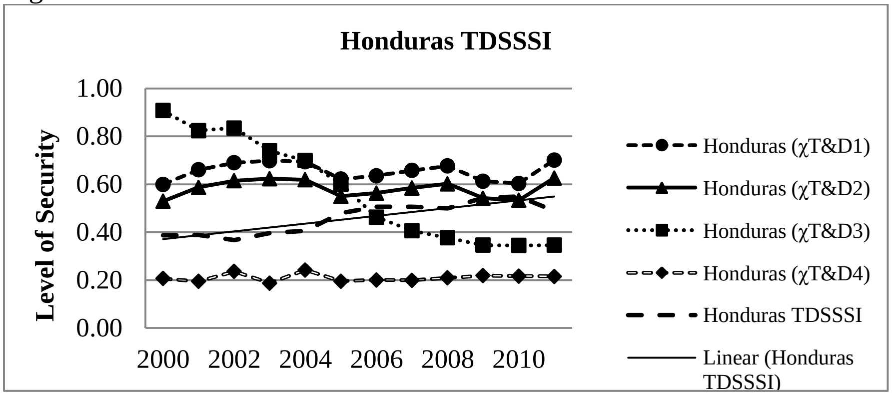


Figure 5.15 presents the performance of the indicators that compose Honduras electricity transmission and distribution systems security of supply index (T&DS). The noticed behavior of the indicators χT&D1 and χT&D2 is that they are decreasing softly its security level over the time as a consequence that electricity demand's growth is faster than the development of new electrical infrastructure associated with transformers and power lines.

These indicators are following a path in way towards 1, which means that risks are increasing and they can affect security of electricity supply. Equipment overuse has affected the power factor but in a minimum level. The reduction in the level of losses was favored as a consequence that automation of substations and the implementation of optical fiber in the grids were accomplished as part of the Central American electrical interconnection (SIEPAC). The undertaken activities have played a significant role in increasing the level of security of supply in the overall systems because technical losses which are represented by the indicator χT&D3 have shown a positive and fast performance.

Honduras T&DS index has increased 10% for both systems during the period under study. The country's T&DS index moved positively from 39% in the year 2000 to 49% in 2011, which is a medium level of security for the entire system. We considered that this variation has been reasonable regardless of the negative performance regarding infrastructure use and the power factor of the systems. As a matter of fact automation is playing positively in reducing technical losses apart from the infrastructure overexertion.

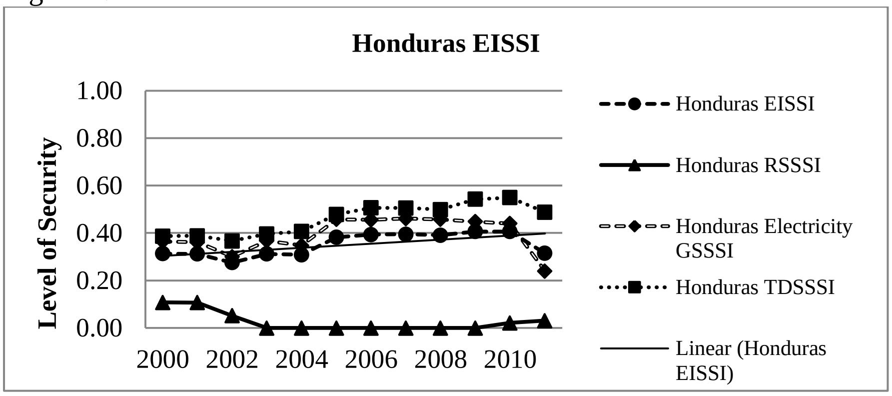
We considered that the country is doing an optimal use of its electrical infrastructure in these systems. In spite of the efficiencies reached in the downstream systems (electricity transmission and distribution systems) and the fact that it is positive for the upstream systems, we believe that they are not significant enough to improve the performance and security level in both the energy resources and the electricity generation systems.

5.1.4.4 Honduras electricity industry security of supply index

Honduras EISSI has shown that the performance of the industry is strictly attached to the resource system outcomes as well as the infrastructure efficiency of the electricity generation system. This country has the lowest level of security of supply for its electricity industry among the Central American nations. Apart from the fact that the performance of the electricity transmission and distribution systems has increased its level of security, it has not been enough as to support the electricity industry's upstream systems. The reduction in the performance of the industry's upstream systems is the main cause of Honduras's EISSI low output.

The theory sets that both energy resources as well as electrical infrastructure have a nominal installed capacity which cannot be exceeded if there are not new additions of infrastructure or technological improvements. This constraint is due to the fact that productive facilities by nature are subjected to their nominal installed capacity and consecutively with their production frontier. Honduras electricity industry has not been prepared to accomplish these activities. Figure 5.16 shows Honduras electricity industry security of supply performance.

Figure 5.16 Honduras EISSI



Based on the analysis of Figure 5.16 we can set that Honduras EISSI has kept the same performance during the last twelve years, although there have been some up and downs, the indicators are still remaining at their initial value of 31% in the year 2000. This is a high low level of security of supply for its electricity industry. We have seen that security of electricity supply cannot improve in this country. This behavior obeys mainly to the fact that the country does not own hydrocarbon resources and the energy mix are based mostly on these types of commodities. Based on these facts, the country is a net importer of energy resources and has been dependent on risky suppliers which also have been highly concentrated. The electricity generation system is composed by technologies based on a single cycle steam power plants, which have a very low level of efficiency. Additionally, the industry has not been effective in building new electrical infrastructure at the same rhythm than demand's growth.

Honduras electricity industry mainly has been affected by the inefficiencies over its electricity generation system which enhances more wastefulness on the energy resource system in order to compensate its lack of generation capacities and needed reserves. The implications for this country in order to achieve security of supply in its electricity industry should start by diversifying and selecting less risky energy resources suppliers as well as employing more renewable energy resources in order to minimize risks and controlling price's fluctuation. Honduras can follow the example of El Salvador. The country needs to implement technologies for electricity production that do not only provide more installed capacities and reserves levels, but also operate at higher levels of efficiency. Policy makers can think in addressing the development of future power plants based on coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment. Finally, the national electricity industry needs to operate under well recognized standards in order to keep an optimal level of security of supply.

5.1.5 Nicaragua's electricity industry

5.1.5.1 Nicaragua's energy resources system

Nicaragua is one nation among the Central American countries which lacks fossil fuel resources due to its own geological nature, but the country has a considerable potential to produce electricity and be self-sufficient based on hydro energy as well as through biomasses as the case of Honduras. Nevertheless, despite of this wealth of renewable energy resources, the nation has not been able to concentrate its energy mixes on these types of resources. The country's energy mix to produce electricity is mainly based on fossil fuels. In other words, the country became a net importer and highly dependent on fossil fuel resources to produce electricity over the time. This nation has experienced price fluctuations in importing hydrocarbons because its prices have been linked to crude oil prices in the international markets. In addition, its electricity industry has been highly dependent on Venezuela, its largest and concentrated supplier. Figure 5.17 shows Nicaragua's energy resources system security of supply performance.

Figure 5.17 Nicaragua’s RSSSI

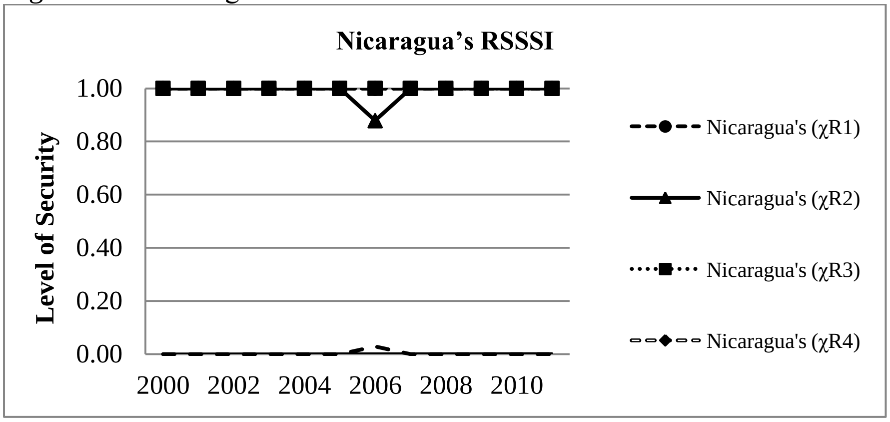


Figure 5.17 shows the performance of the indicators that compose Nicaragua’s energy resources system security of supply index (RS). The observed behavior for all the χR indicators in general is that all of them are over 1. These situations reflect that Nicaragua’s electricity industry has the lowest performance regarding security of supply in its energy resource system. As we set before it is because the country does not own and produce fossil fuels for its own consumption. Based on the energy mix to produce electricity the country is a net importer and highly dependent on fossil fuels. The risks on price fluctuations are present since the country has been high dependent and concentrated from one single supplier over the time which is considered as a risky partner in term of international trade due to its instable politics. The country’s RS index did not improve during the period under study since it remains in 0, which is the lowest level of security for the system.

The performance of the Nicaragua’s RS index has decreased from 62% in the year 2000 to 48% in 2011. The index is decreasing towards 0 and it means that the level of security of supply on the energy resources system is getting lower. We consider that this variation during the period under study has been considerable and it has been as a consequence of the lack of fossil fuel resources, dependency on imports as well as the own nature of the power plants infrastructure. Probably by changing the country's energy mix to produce electricity based on renewable as well as coal energy resources the electricity industry can improve security of supply. By these means the country can be able to decrease concentrated dependency on fossil fuel imports, price fluctuations as well as decrease risks on depending from one single and risky supplier. Nicaragua can implement similar measures as the ones followed by El Salvador to reach high an acceptable growth in the security level for the overall system.

5.1.5.2 Nicaragua's electricity generation system

Nicaragua's electricity generation system was unbundled in order to promote competitiveness through private participation. After deregulation the system's infrastructure growth depends on the Nicaraguan Energy Institute (INE), which was the largest SOE before liberalization. The strategy is the same as the one employed in the cases of Guatemala and El Salvador. Currently there are 20 different private participants own 78.68% of the installed capacities, while government owns just 21.32%. This is the country case with the lowest governmental participation in terms of electricity production. The State has decreased its participation considerably although it operates permanently based on hydro power and geothermal power facilities. INE has minor market participation in the power market for around 13.92%. The country's Installed power capacity at the year 2011 was around 1.11 GW. The development of new power plants growth has registered an average annual growth of 5.04% during the period under study. At the year 2011 Nicaragua was 63% dependent from thermal power (oil commodities), 23% from geothermal power, and 14% from hydroelectricity.

Domestic production of electricity at the year 2011 reached 3.43 TWh while consumption represented 2.7 TWh. The differences do not mean that the country is a net exporter of electricity. As a matter of fact, this nation is a net importer of electricity from the Central American electricity market, and the differences obey to high level of technical and non-technical losses on the electricity transmission and distribution systems. The challenges for Nicaragua's electricity generation system are to develop future power plants based on renewable energy resources and technologies in order to reduce its high dependency from fossil fuels. Also, it is required to select technologies with high levels of operational efficiency in order to meet standards. The system's performance tends to be affected by the infrastructure's inefficiencies as well as negative environmental issues, which are a common characteristic of the region. Figure 5.18 shows Nicaragua's electricity generation system security of supply performance.

Figure 5.18 Nicaragua’s GSSSI

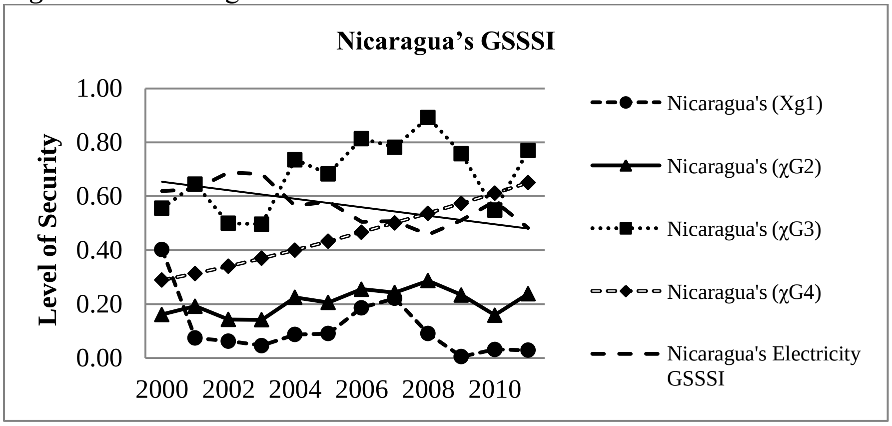


Figure 5.18 shows the performance of the indicators that compose Nicaragua’s electricity generation system security of supply index (GS). The observed behavior on the indicators χG2, χG3, and χG4 is that all of them are increasing towards 1. This situation reflects the increase of risks a reduction in the overall level of security for the GS index. However it is possible to see that the performance of χG1 has improved and it has been by means of adding new installed capacities, upgradings or accomplishing maintenances on time in the core equipment of power plants. These actions probably have favored the behavior of χG2 which has been stable during the period under study. Additionally, they might be the reason of the dynamic behavior of χG3, although it is not in an optimal level but it is comprehensible because it is susceptible to be affected by electricity demand’s growth as well as the equipment ages χG4 which is increasing steadily.

The performance of the Nicaragua’s GS index has decreased from 36% in the year 2000 to 24% in 2011. The index is decreasing towards 0 which means that the level of security of supply of the generation system is getting lower. We considered that this variation during the period under study has been measured and it has been as a consequence of the own nature of the generation infrastructure as well as its age. If new additions of installed capacities are not accomplished in the coming years the country may not be able to counter the demand's requirements by itself and also can increase its dependency on electricity imports. We believe that reducing the dependency from fossil fuels as well as selecting other type of technologies with high level of efficiencies to produce electricity can stimulate a positive impact on the level of security of the overall system. Policy makers can think in focusing on the development of future power plants based on coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment.

5.1.5.3 Nicaragua's electricity T&D systems

Nicaragua's electricity transmission and distribution systems are owned and operated by both State and privates. Electricity transmission is operated by the governmental state owned enterprise, Empresa Nacional de Transmisión Eléctrica (ENATREL), while electricity distribution is unbundled into 2 companies which are owned and operated by private consortiums. The distribution companies were unbundled geographically. The systems have an installed capacity at the year 2011 of 2,551 kilometers in power lines, while 3,543 MWA in transformer capacities. Infrastructure development has growth at 4.18% in average per annum, while electricity demand has growth to 4.75% in average per annum. The margins between infrastructure development and demand's growth do not allow the systems to count with enough reserves and operate out of technical limits settled on standards.

The level of losses represents almost 25% of total production of domestic electricity. Total electricity coverage in Nicaragua is 77.7% (2009), being almost 97.9% in urban areas and around 46.6% in rural ones. The average number of interruptions annually per customer is around 4, while its duration is around 10.54 minutes in urban areas. Electricity price at the year 2011 was in average US $ 0.2362 per kWh and this high costs obeys to the high dependency using fossil fuels to produce electricity. The main challenges for both systems are the development of a more durable infrastructure that responds to demand's requirements on time as well as work under technical standards to improve efficiency and security of supply. Figure 5.19 presents Nicaragua's electricity transmission and distribution systems security of supply performance.

Figure 5.19 Nicaragua's TDSSSI

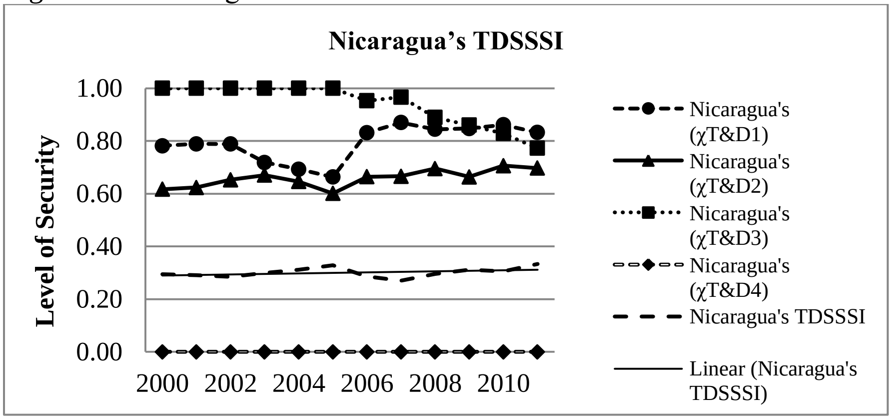


Figure 5.19 presents the performance of the indicators that compose Nicaragua's electricity transmission and distribution systems

security of supply index (T&DS). The noticed behavior for the indicators χT&D1 and χT&D2 is that they are decreasing softly its security level over the time as a consequence that electricity demand's growth is faster than the development of new electrical infrastructure associated with transformers and power lines. Those indicators are following a path in way headed to 1, which means that risks are increasing and they can affect security of electricity supply. Equipment overexertion may affect the level of technical losses as well as the power factor. However, these situations have been minimized as an outcome of automation of substations and the implementation of optical fiber on power grids. These activities were accomplished as part of the Central American electrical interconnection (SIEPAC) and they have played a significant role in increasing the level of security of supply in the overall systems due to technical losses which are represented by the indicator χT&D3that have shown a positive performance.

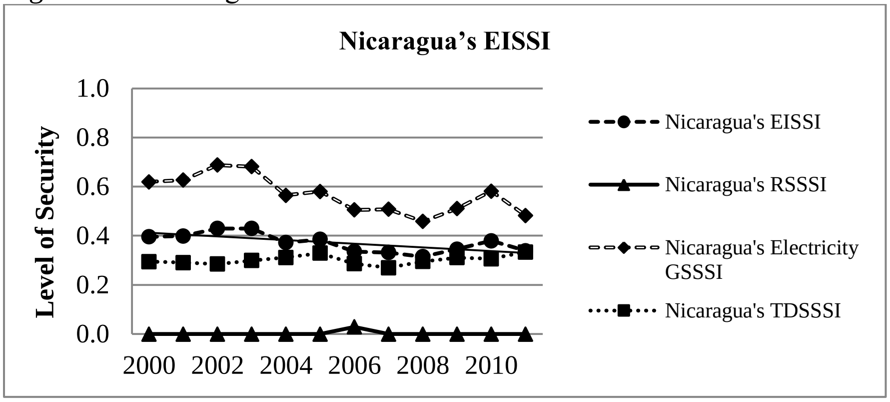
Nicaragua's T&DS index has increased 4% for both systems during the period under study. The country's T&DS index moved positively from 29% in the year 2000 to 33% in 2011, which is a low level of security for the entire system. The efficiencies gained by reducing the level of technical losses (χT&D3) favored the behavior of the indicator χG3 (reserve capacities) as we can compare from both Figures 5.18 and 5.19 since the year 2008. However, in spite of the reached achievements during the period under study, we can see that the performance of Nicaragua's χT&DS index is still low. This situation complies with the fact that the level of non-technical losses in the electricity distribution system is still high, around 10%. More efforts are needed to be attained in order to follow technical standards and by these means reach higher level of efficiency in the electricity industry's downstream systems in order to impact positively the upstream systems and the overall electricity industry security of supply performance.

5.1.5.4 Nicaragua's electricity industry security of supply index

Nicaragua's EISSI has shown that the performance of the industry is strictly attached to the resource system outcomes as well as the infrastructure efficiency. The country has a low high level of security due to its volatile performance in the energy resources as well as in the electricity generation system. Although its electricity transmission and distribution systems have increased its level of security this has not been significant as to improve the overall performance regarding security of supply on the electricity industry.

The reduction in the performance on the electricity industry's upstream systems is the main cause of Nicaragua's EISSI low output. The theory sets that both energy resources as well as electrical infrastructure have a nominal installed capacity which cannot be exceeded if there are not new additions of infrastructure or technological improvements. This constraint is due to the fact that productive facilities by nature are subjected to their nominal installed capacity and consecutively with their production frontier as the case of power plants in this country. Figure 5.20 shows Nicaragua's electricity industry security of supply performance.

Figure 5.20 Nicaragua's EISSI



Based on the analysis of Figure 5.20 we can set that Nicaragua's EISSI has decreased from 40% in the year 2000 to 34% in 2011. We have seen that Nicaragua's electricity industry security of supply level has decreased stately. It falls down from a medium level to a low high level during the period under study. As a matter of fact, the main causes in decreasing the country's EISSI have been the fact that the country does not own hydrocarbon resources and its energy mix is based mostly on these types of energy commodities to produce electricity. Based on these certainties, the country is a net importer of energy resources and has been dependent on a risky supplier which also has been highly concentrated. The electricity generation system is composed by technologies based on a single cycle steam power plants, which have a very low level of efficiency. Additionally, the industry has not been effective in building new electrical infrastructure at the same rhythm as the demand's growth as well as following technical standards in the electricity industry's downstream systems (electricity transmission and distribution systems).

Nicaragua's electricity industry has been affected by a 'chain effect' in which the downstream systems, which are closer to the demand and are susceptible of its effects, raise the upstream systems in order to compensate their inefficiencies. The implications for this country in order to achieve security of supply in its electricity industry should start by diversifying and selecting less risky energy resources suppliers as well as employing more renewable energy resources in order to minimize risks and practice control over price's fluctuation. The country needs to implement technologies for electricity that do not only provide more installed capacities and reserves levels, but also operate at higher levels of efficiency.

The electricity transmission and distribution infrastructure need to be strong by means of automation and increase power lines coverage. These actions are required in order to mitigate congestion and overexertion problems, and it can be through building parallel lines, increasing voltage levels or developing distributed generation systems closer to demand. Finally, the national electricity industry needs to operate under well recognized standards in order to keep an optimal level of security of supply.

5.1.6 Costa Rica's electricity industry

5.1.6.1 Costa Rica's energy resources system

Costa Rica is one of the Central American countries which lack fossil fuel resources because of its own geological nature, but the country has a considerable potential to produce electricity and be self-sufficient based on hydro energy as well as through biomasses as in the case of Honduras. As a matter of fact, this nation has been doing well in utilizing its domestic renewable energy resources to produce electricity and cover the electricity demand's growth consumption. The country's energy mix to produce electricity is based on around 76% in hydro power. However, the country still need to import both electricity and fossil fuels to compensate demand requirements and for the foregoing reasons it is a net importer. A positive fact is that Costa Rica has diversified and distributed in a better way its number of suppliers for hydrocarbons in order to mitigate risks regarding price fluctuations or shortages. Figure 5.21 shows Costa Rica energy resources system security of supply performance.

Figure 5.21 Costa Rica's RSSSI

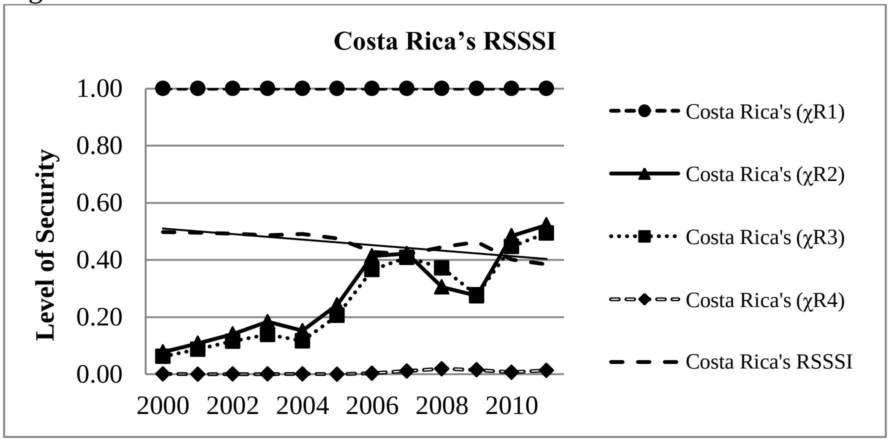


Figure 5.21 shows the performance of the indicators that compose Costa Rica energy resources system security of supply index (RS). In one hand, for geological issues the country lacks hydrocarbon resources therefore the negative performance of $\chi R1$ cannot be improved. On the

other hand, the observed behavior of the indicators χR2, χR3, and χR4 in general is that all of them are growing in direction towards 1. These situations reflect that Costa Rica RS index is decreasing its performance in terms of security of supply. The changes that Costa Rica has accomplished in its energy mix to produce electricity are the main causes that have affected the performance of the indicators χR2, χR3, and χR4. The country's electricity industry during the period under study has accomplished the development of thermoelectric power plants based on hydrocarbons. Costa Rica became a net importer of energy resources in order to produce electricity and satisfy electricity demand's requirements.

The performance of Costa Rica RS index has decreased from 50% in the year 2000 to 38% in 2011. The index is decreasing towards 0 that means that the level of security of supply in the energy resources system is getting lower. We considered that this variation during the period under study has been considerable and it has been as a consequence of the lack of fossil fuel resources and its dependency on imports. If there are limitations to accomplish the development of renewable energy projects, policy makers may consider to implement similar measures as the ones followed by El Salvador to reach an acceptable level of growth in terms of security for the overall system. Furthermore, they also can consider the development of future power plants based on coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment in order to improve security levels for the country's energy resource system.

5.1.6.2 Costa Rica's electricity generation system

Costa Rica electricity generation system has large participation of the state owned enterprise, which is the Instituto Costarricense de Electricidad (ICE). Currently there are 39 public companies constituted under the cooperative model, and centralized by ICE. Additionally, there are 27 independent power producers. ICE owns 86% of the country's generation facilities, while privates own just 14% of installed capacities. ICE's market share is for around 84% since 73% of its facilities are based on renewable energy resources and technologies. The other 27% of ICE's power plants are based on thermal power and it is as a strategy to reduce the negative environmental effects over the production of hydro power. The country's Installed power capacity at the year 2011 was around 2.65 GW. The development of new power plants growth has registered an average annual growth of 4.16% during the period under study.

The electricity industry depends on 76% from hydro power, 17% from geothermal power and biomasses, and 7% from thermal power based on crude oil commodities. Domestic production of electricity at the year 2011 reached 9.76 TWh while consumption represented 8.87 TWh. The country exported 0.005 TWh to the Central American electricity market. The challenge for Costa Rica electricity generation system is to continue developing future power plants based on renewable energy resources and technologies in order to meet demand requirements through a friendly energy mix. The idea is to continue providing reasonable prices of the supply of the electricity service for the different sectors of the national economy. The system's performance tends to be affected by infrastructure's inefficiencies as well as negative environmental issues, which are a common characteristic of the region. Figure 5.22 illustrates Costa Rica electricity generation system security of supply performance.

Figure 5.22 Costa Rica's GSSSI

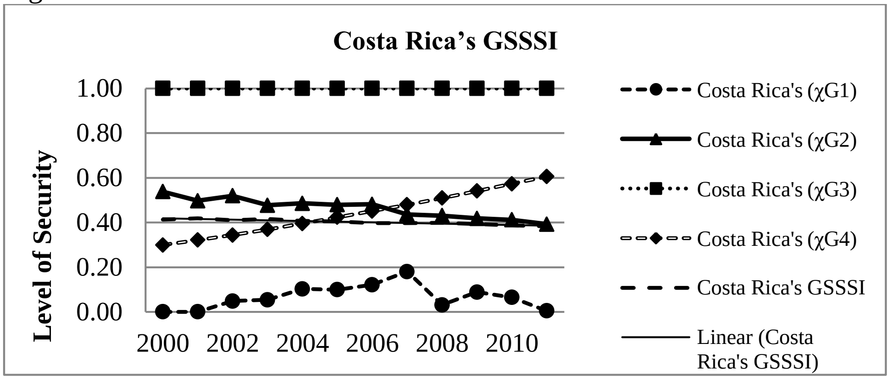


Figure 5.22 shows the performance of the indicators that compose Costa Rica electricity generation system security of supply index (GS). The observed behavior for all the indicators χG3 and χG4 in general is that they are decreasing their performance and they are contributing in reducing the overall level of security of the GS index. In one hand, for geological issues the country lacks hydrocarbon resources and the instability of renewable energy resources and thus the country became a net importer of hydrocarbons as well as electricity from neighboring nations. However it seems that electricity imports (χG2) have started to be minimized and it can be possible through the addition of new installed capacities (χG1) but this has not been enough to keep appropriate levels of reserves (χG3) and they may be also affected by the power plants' ages (χG4). The addition of power capacities based on thermal power plants do not allow to reach high levels of efficiency and it also affects the reserves levels.

The performance of Costa Rica GS index has decreased from 41% in the year 2000 to 38% in 2011. The index is decreasing towards 0 which means that the level of security of supply of the energy resources system is getting lower. We considered that this variation during the period under study has been soft and it has been as a result that the electricity generation system is still highly dependent on renewable energy resources. The changes in the energy mix and the type of employed technologies are the main causes for decreasing the performance of the overall energy resources system.

The levels of effective capacities and reserves are attached to age of equipment as well as the preciseness of maintenances and upgradings. Policy makers in this country might consider the development of future power plants based on coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment in order to improve security levels for the country's energy resource system.

5.1.6.3 Costa Rica's electricity T&D systems

The Costa Rican electricity transmission and distribution systems are owned and operated by the Instituto Costarricense de Electricidad (ICE), which is a state owned enterprise. However, this public utility is also associated with the operation of the grid with a series of cooperatives. In these systems private participation has not been allowed yet and it remains as a pure state monopolistic model since ICE centralize the operational policies. The systems have an installed capacity at the year 2011 of 1,913 kilometers in power lines, while 7,606 MWA in transformer capacities. Infrastructure development has growth at 2.09% in average per annum, while electricity demand has growth of 4.05% in average per annum. The margins between infrastructure development and demand's growth do not allow the systems to count with enough reserves and operate out of technical limits settled on standards.

Total electricity coverage in 2011 was 99.1%, being 100% in urban areas and around 97.7% in rural ones. During the same year the average numbers of interruptions annually per customer in urban areas were 5, while the average duration times were 15.05 minutes. In addition, electricity prices are subsidized through fiscal resources, they represented in average US $ 0.1486 per kWh. The main challenges for both systems are the development of a tougher infrastructure that responds to demand's requirements on time as well as works under technical standards to improve efficiency and security of supply. Figure 5.23 presents Costa Rica electricity transmission and distribution systems security of supply performance.

Figure 5.23 Costa Rica's TDSSSI

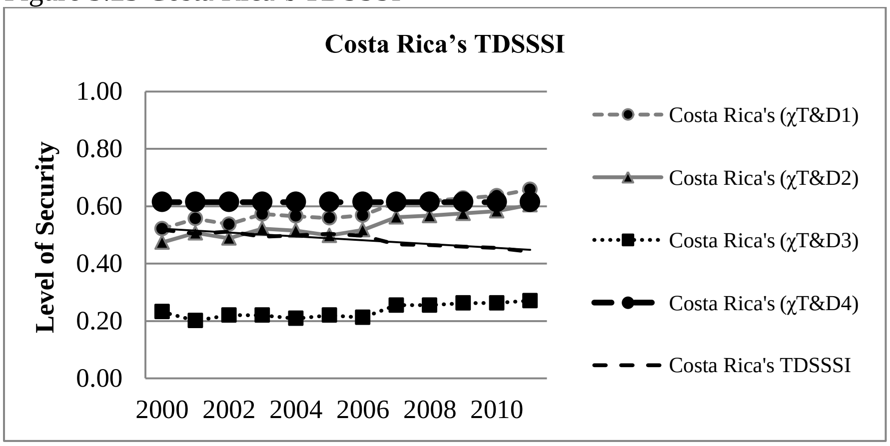


Figure 5.23 shows the performance of the indicators that compose Costa Rica electricity transmission and distribution systems security of supply index (T&DS). The noticed behavior of the indicators χT&D1, χT&D2 and χT&D3 is decreasing softly its performance over the time as a consequence that electricity demand's growth is faster than the development of new electrical infrastructure associated with transformers and power lines. These facts have affected existent equipment since they have been overdone. Although, these negative situations, the country has undertaken efforts in order to mitigate losses by means of accomplishing automation of substations and improving remote communications with the implementation of optical fiber on power grids as part of the Central American electrical interconnection (SIEPAC). In this case automation has been effective in reducing the level of technical losses in the electricity transmission system but it has not been the case of the electricity distribution system which has a more dynamic nature and it affected negatively Costa Rica T&DS index.

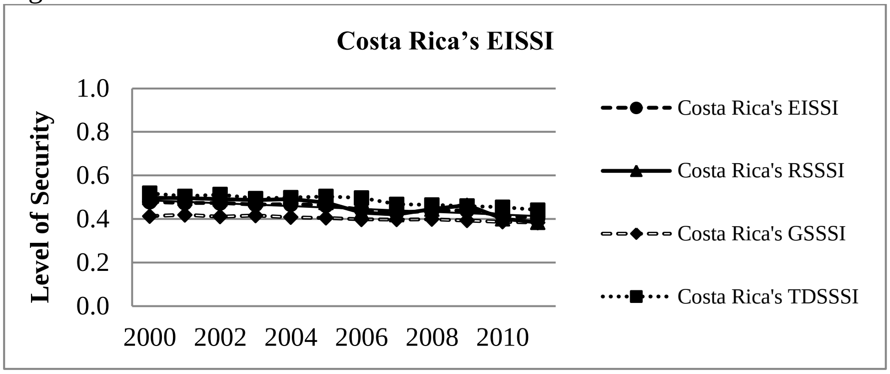
Costa Rica T&DS index has decreased 8% for both systems during the period under study. The country's T&DS index moved negatively from 52% in the year 2000 to 44% in 2011, which is a medium level of security for the entire system. We considered that this variation is reasonable based on the negative performance of infrastructure. The decrease in Costa Rica T&D index is as a result of growing demand and because the entire electrical infrastructure that is required has not been developed yet at the same rhythm as the demand's growth. As a consideration, we have increased those inefficiencies in the downstream systems (electricity transmission and distribution systems) as well as the inefficiencies in the upstream systems in order to compensate the ‘losses’.

These actions are required in order to mitigate congestion, overexert problems, reduce technical and non-technical losses through building parallel lines, increase voltage levels, develop distributed generation systems closer to demand, and implement smart metering. Finally, the national electricity industry needs to operate under well recognized standards in order to keep an optimal level of security of supply.

5.1.6.4 Costa Rica’s electricity industry security of supply index

Costa Rica EISSI has shown that the performance of the industry is strictly attached to the resource system outcomes as well as the infrastructure efficiency. The country has a medium level of security of supply in its electricity industry due to the fact that the energy resources systems as well as the electricity generation productive infrastructure are supported by renewable energy resources and technologies. This fact is the main cause for maintaining the level of output for Costa Rica EISSI. However renewable energy resources are suffering of environmental phenomena as well as social resistance for the development of new projects that contribute to increase installed capacities and reserves as well as reduce the imports of fossil fuel resources and electricity from neighboring countries. Figure 5.24 shows Costa Rica electricity industry security of supply performance.

Figure 5.24 Costa Rica's EISSI



Based on the analysis of Figure 5.24 we can set that Costa Rica EISSI has decreased. Costa Rica EISSI has decreased in a reasonable way from 48% in the year 2000 to 40% in 2011. We have seen that Costa Rica electricity industry security of supply level has decreased in a reasonable way. The electricity industry security of supply level still remains between the medium ranges during the period under study. As a matter of fact, the main causes in decreasing the country's EISSI have been the fact that the country does not own hydrocarbon resources and its energy mix is decreasing the production of electricity based on renewable energy resources due to its instability as well as social resistance for the accomplishment of new projects and negative environmental effects, which are the same characteristics of the Latin American countries with access to the Pacific Ocean.

Costa Rica electricity industry has not been effective in building new electrical infrastructure at the same rhythm as the demand's growth as well as following technical standards in the electricity industry's downstream systems (electricity transmission and distribution systems). The electricity distribution infrastructure needs to be strong by means of automation and operate under well recognized standards in order to keep an optimal level of security of supply. These actions are required in order to mitigate congestion and overexertion problems, and it can be through building parallel lines, increasing voltage levels or developing distributed generation systems closer to demand. The country needs to implement technologies for electricity production that not only provide more installed capacities and reserves levels, but also operate at higher levels of efficiency. For the preceding reasons, policy makers might consider the development of future power plants based on coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment in order to improve security levels for the overall electricity industry.

5.1.7 Panama's electricity industry

5.1.7.1 Panama's energy resources system

Panama is a nation that lacks fossil fuel resources for its own geological nature, but the country has a considerable potential to produce electricity and be self-sufficient based on hydro energy as well as through biomasses means. In spite of this wealth of renewable energy resources the nation has not been able to modify its energy mix from fossil fuels to renewables. This country has increased the employment of hydrocarbons from 31% in the year 2000 to 43% in 2011. In other words, the country became a net importer and highly dependent on fossil fuel resources to produce electricity over the time. This nation has experienced price fluctuations in importing fossil fuels because its prices have been linked to crude oil prices in the international markets. In addition, Panama has been highly dependent on Venezuela, Ecuador or the U.S. as largest suppliers and in any of the cases these nations have been highly concentrated in their supplies. Figure 5.25 shows Panama's energy resources system security of supply performance.

Figure 5.25 Panama's RSSSI

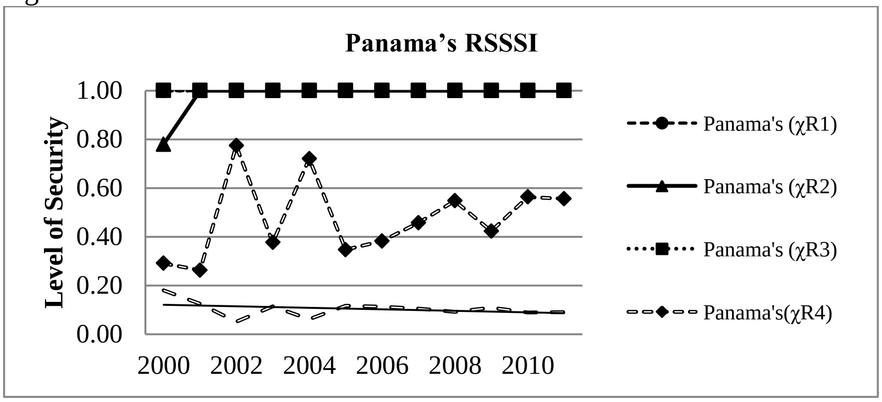


Figure 5.25 shows the performance of the indicators that compose Panama's energy resources system security of supply index (RS). The observed behavior of the indicators χR1, χR2, and χR3 is that all of them are over 1. These situations indicate that Panama's electricity industry has a lower performance regarding security of supply in its energy resource system. In addition the indicator χR4 is increasing because the energy resources system is increasing the concentration of its energy mix on the use of fossil fuels to produce electricity. As we set before it is because the country does not own and produce fossil fuels for its own consumption and thus becoming highly dependent on fossil fuels imports. The risks on price

fluctuations are there since the country has been highly dependent and concentrated on one single supplier over the time. The country's RS index did not improve during the period under study since it remains in 0, which is the lowest level of security for the system.

The performance of Panama's RS index has decreased from 18% in the year 2000 to 9% in 2011. The index is decreasing towards 0 which indicates that the level of security of supply in the energy resources system is getting lower. We considered that this variation during the period under study has been considerable and it has been as a result to the lack of fossil fuel resources and imports dependency from concentrated suppliers. Probably by changing the country's energy mix to produce electricity based on coal energy resources the electricity industry can improve security of supply. This implication is based on the fact that Panama's renewable energy resources are susceptible of the negative effects of natural phenomena. By these means the country can be able to decrease concentrated dependency on fossil fuel imports, price fluctuations as well as decrease risks on depending from one single and risky supplier. Panama can implement similar measures as the ones followed by El Salvador to reach an acceptable level of growth regarding security for the overall system.

5.1.7.2 Panama's electricity generation system

Panama's electricity generation system was unbundled in order to promote competitiveness through private participation. Deregulation employs the sale of assets as well as allows private participants growth around the country's facilities and currently 34 different power plants which own 84% of the installed capacities, while government owns just 16%. Private companies have a market share for around 86%. Panama's installed power capacity at the year 2011 was around 2.39 GW. The country depends 56% on hydro power, 43% on thermal power, and 1% on other kind of renewable power. Domestic production of electricity at the year 2011 reached 7.80 TWh while consumption represented 7.38 TWh.

In one hand, regardless of the difference, the country is not performing as a net exporter of electricity since the level of losses represents almost 15% of total production of domestic electricity. On the other hand, the electricity industry needs to import electricity from the Central American electricity market in order to compensate those inefficiencies as well as mitigate negative effects produced by natural phenomena. The country is aiming to develop new thermal power plants based on coal in order to mitigate negative effects produce by natural phenomena. Figure 5.26 shows Panama's electricity generation system security of supply performance.

Figure 5.26 Panama's GSSSI

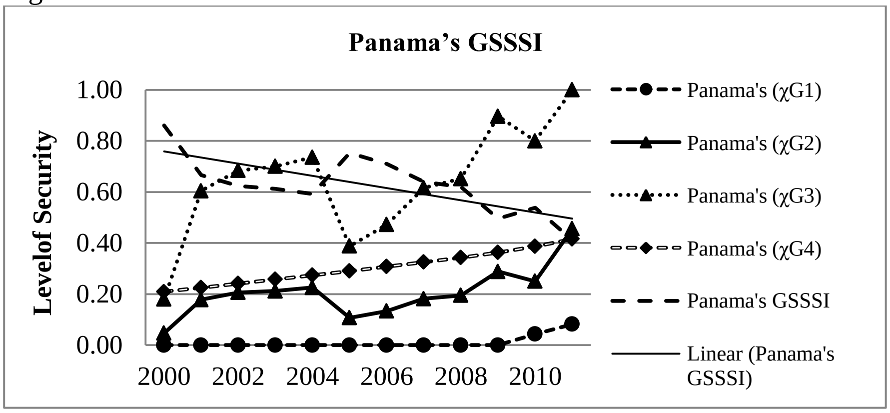


Figure 5.26 presents the performance of the indicators that compose Panama's electricity generation system security of supply index (GS). From one perspective, the nature of $\chi G1$ seems to be more conservative than the other indicators and it is decreasing its performance as a consequence of the accomplished changes regarding the energy mix. Panama has been trying to expand its electricity generation system through accomplishing the development of new power plants based on thermoelectric technologies that have a low productive output. Also, large hydro power plants are being affected by its age factor which is growing progressively. From another perspective, the observed behavior of the indicators $\chi G2$, $\chi G3$, and $\chi G4$ means that they are closer to 1 or at least are going up in that direction. These situations reflect a low performance of those indicators and jeopardize the entire system. The main causes of the low performance of these indicators have been electricity demand's growth which has been faster than the development of new energy projects as well as the negative effects of natural phenomena.

The reduction of the level of reserves in Panama's electricity generation system follows negative environmental issues as well as the low productive output of thermo power plants. These situations are triggering the nation to be a net importer of electricity from neighboring countries. The performance of the country's GS index has decreased from 18% in the year 2000 to 9% in 2011, which is a medium low level of security. We considered that this variation during the period under study has been constant, and it follows the own nature of the electricity generation infrastructure.

The behavior of Panama's GS index is decreasing towards 0 which means that the level of security of supply in the generation system is getting low. We believe that reducing the dependency from fossil fuels as well as selecting other type of technologies with high level of efficiencies to produce electricity can stimulate a positive impact on the level of security of the overall system.

5.1.7.3 Panama's Electricity T&D systems

Panama's electricity transmission and distribution systems are owned and operated by both State and private sector. Electricity transmission is operated by the governmental state owned enterprise, Empresa de Transmisión Eléctrica Panameña (ETESA), while electricity distribution is unbundled into 3 companies which are owned and operated by private consortiums. The distribution companies were unbundled geographically. The systems have an installed capacity at the year 2011 of 2,152 kilometers in power lines, while 1,787 MWA in transformer capacities. Infrastructure development has growth of 3.10% in average per annum, while electricity demand has growth at 4.62% in average per annum. The margins between infrastructure development and demand's growth do not allow the systems to count with enough reserves and operate out of technical limits settled on standards.

The level of losses represents almost 15% of total production of domestic electricity. Total electricity coverage in 2011 was 90.45%, being almost 98.9% in urban areas and around 82% in rural ones. The average number of interruptions annually per customer in urban areas was around

8, while its duration was around 10.03 minutes. Electricity prices are settled under market mechanisms in the electricity generation system; however, the government provides subsidies for the customers. At the year 2011 electricity service price was in average US $ 0.1725 per kWh. The main challenges for both systems are the development of a tougher infrastructure that responds to demand requirements on time and works under technical standards to improve efficiency and security of supply. Figure 5.27 shows Panama's electricity transmission and distribution systems security of supply performance.

Figure 5.27 Panama's TDSSSI

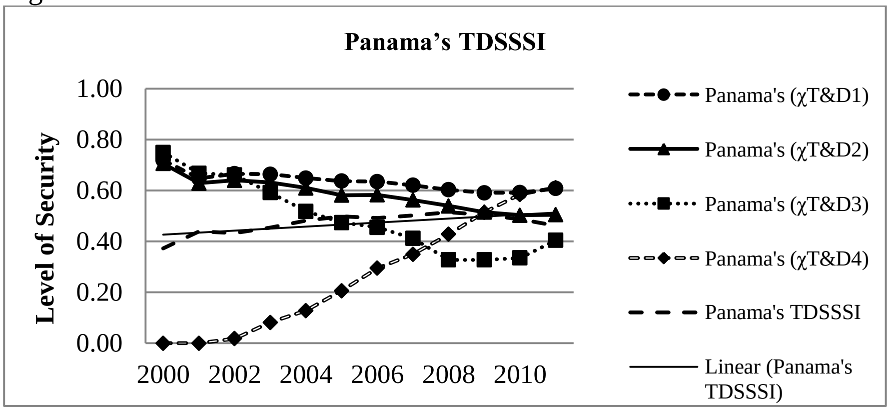


Figure 5.27 illustrates the performance of the indicators that compose Panama's electricity transmission and distribution systems security of supply index (T&DS). The observed behavior of the indicators χT&D1, χT&D2, and χT&D3 explains that the systems have been accomplishing the development of new electrical infrastructure associated with transformers and power lines. Those indicators are following a path far away form 1, which means that risks are decreasing and it improves

security of electricity supply. However equipment overuse has affected the power factor indicator (χT&D4). This situation is as a consequence that Panama is an emerging economy and the electricity distribution system is more dynamic because it is closer to demand's side which is under expansion and it tends to produce this negative effect over the referred indicator. The reduction in the level of losses was favored as a consequence that automation of substations and the implementation of optical fiber on the grids were accomplished as part of the Central American electrical interconnection (SIEPAC).

Panama's T&DS index has increased 9% for both systems during the period under study. The country's T&DS index moved positively from 37% in the year 2000 to 46% in 2011, which is a medium level of security for the entire system. We considered that this variation has been reasonable despite of the negative performance of the power factor. The undertaken activities have played a significant role in increasing the level of security of supply in the overall systems because of technical losses which are represented by the indicator χT&D3 have shown a positive and fast performance.

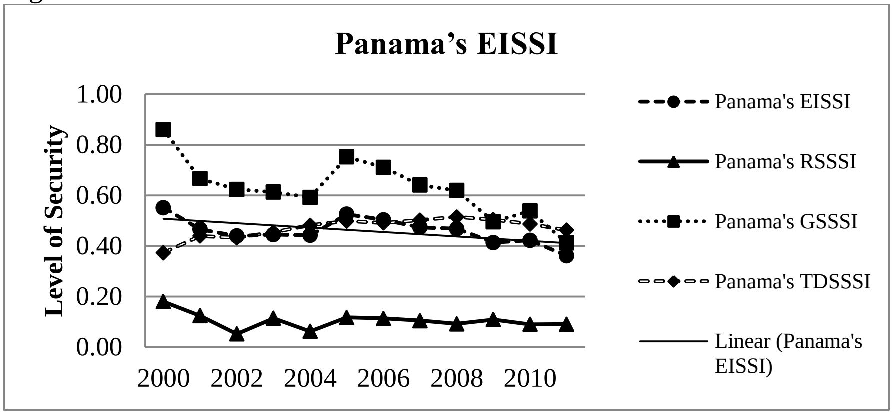
The level of risk regarding technical and non-technical losses decreased during the period under study from 70% in the year 2000 to 40% in 2011. However, the electricity transmission and distribution systems need to operate under well recognized standards in order to keep an optimal level of security of supply and mitigate the negative effects of the dynamic nature of the electricity distribution system.

5.1.7.4 Panama's electricity industry security of supply index

Panama's EISSI has shown that the performance of the industry is strictly attached to the resource system outcomes as well as the infrastructure efficiency. The country's electricity industry has a medium low level of security of supply because the negative situations that have contributed in decaying the performance of the energy resources as well as in the electricity generation system. The negative effects of demand's growth, which has been faster than the development of new energy projects, as well as the negative effects of the natural phenomena El Niño and La Niña have played a vital role decreasing the electricity industry's overall security of supply performance.

Although the electricity transmission and distribution systems have increased its level of security of supply they require attention in order to improve the performance of the power factor and control future increments of technical losses. The reduction of Panama's EISSI performance and low output has been as a result of the upstream industry's systems. Figure 5.28 shows Panama's electricity industry security of supply performance.

Figure 5.28 Panama's EISSI



Based on the analysis of Figure 5.28 we can appoint that Panama's EISSI has decreased from 55% in the year 2000 to 36% in 2011. This is the most dramatic case of reducing the overall level of security of supply for its electricity industry in this study. We have seen that security level has decreased faster and considerably, since it diminished 19% during the period under study. As a matter of fact, the main causes in decreasing Panama's EISSI have been the negative effects of demand's growth, which has been faster than the development of new energy projects, as well as the negative effects of the natural phenomena El Niño and La Niña.

These factors have also supported the development of new power plants based on fossil fuel resources and changing the country's energy mix for producing electricity. Furthermore, these situations have made Panama a net importer of hydrocarbon resources and electricity over the time. The infrastructure employed to produce electricity cannot reach optimal levels of efficiency either because the lack of resources due to natural phenomena or because of the nature of the equipment. Panama's electricity industry is limited to offer reserves capacities because of these matters.

Panama's' electricity industry has been affected mainly by issues positioned on the electricity industry's upstream systems, which are susceptible for demand's growth effects as well as natural phenomena issues. The industry has not been effective in increasing electrical infrastructure capacities as well as diversifying its energy mix for producing electricity. New energy projects have not been accomplished at the same pulse as the demand's growth.

Panama's policy makers can address for the development of future power plants, the adoption of coal or integrated gasification combined cycle technologies supplied with pollution abatement equipment. These actions are to stimulate a positive impact on the level of security of supply for overall electricity industry. By these means the nation can access other kinds of energy resources as well as increase power generation capacities. Coal can be a solution since Colombia is one of the largest suppliers in Latin America and is closer to Panama and thus reducing freight costs.

5.1.8 Colombia's electricity industry

5.1.8.1 Colombia's energy resources system

Colombia is a net exporter of hydrocarbons, without processing or transformation, which also has affected negatively in reducing its proven reserves of fossil fuels. However the country has implemented accurate policies and one of them has been the creation of Ecopetrol, which business model has been a factor to enhance the country's potential in terms of hydrocarbons. The country has been able to accomplish new discoveries and additions during the period under study and has shown a dynamic performance in this regard. Additionally, this is one of the Latin American nations which have strong potential to produce electricity and be self-sufficient based on hydro energy as well as biomasses. As a matter of fact, this nation has been doing the effective use of its domestic renewable energy resources to produce electricity and cover the electricity demand's growth consumption. The country's energy mix to produce electricity is based on around 72% of hydro power and is a net exporter of electricity to neighboring countries.

Additionally, the same as some Latin American countries with hydro power potential, Colombia is facing social resistance for the construction of hydropower plants as well as negative environmental effects. The natural phenomena of El Niño and La Niña are a common threat for this nation that has access to the Pacific Ocean. Colombia intends to mitigate the negative effects generated by these environmental issues on the production of renewable energy resources through the employment of fossil fuel resources in its energy mix, which are employed under reasonable parameters of concentration. In terms of coal the country is self-sufficient in terms of resources' availability, while it depends on the imports of processed crude oil commodities as well as natural gas from regional suppliers. The only constraint is the fact that these energy resources are subject to levels of production as well as the proven reserves lifespan. Figure 5.29 shows Colombia's energy resources system security of supply performance.

Figure 5.29 Colombia’s RSSSI

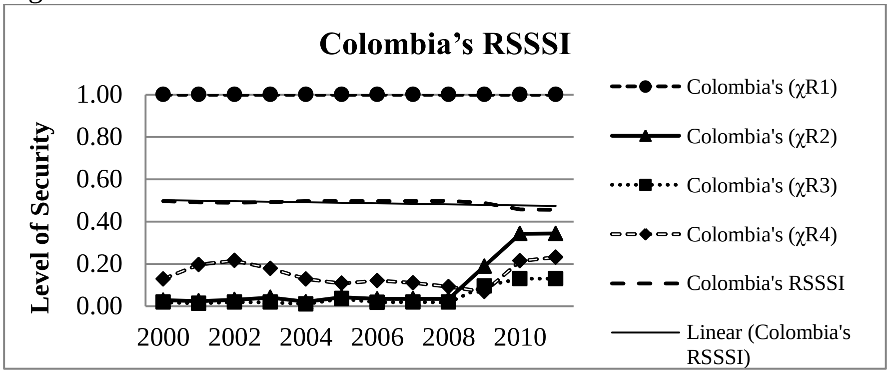


Figure 5.29 shows the performance of the indicators that compose Colombia energy resources system security of supply index (RS). In one hand, Colombia is not considered as a worldwide producer of crude oil and for the prior reasons the proven reserves indicator χR1 pathway tends to be placed inside the risky levels and cannot be improved if new and considerable discoveries are not accomplished in order to increase the level of proven reserves and surpass the constraint of production levels. On the other hand, because of natural phenomenon issues, the country tends to reduce periodically the domestic production of renewable energy resources and as a consequence is the negative performance of the indicators χR2, χR3, and χR4. Since the year 2008 Colombia increased the consumption and imports of fossil fuel resources to produce electricity. These situations can be a result that the country confronted the rise in the number of floods per annum, which might have affected the production of water and biomasses. Sediments’ accumulations in watersheds as well as dams tend to decrease the production of water for hydroelectricity production.

The performance of Colombia RS index has decreased from 50% in the year 2000 to 46% in 2011. The index is decreasing which means that the level of security of supply of the energy resources system is getting lower. We considered that this variation during the period under study has not been significant along with the period under study but it has affected the performance of the overall system. The negative impacts have been modify in some way the electricity industry's energy mix and increase the dependency on imports of fossil fuel resources which are subjected to price fluctuations. If there are limitations to accomplish the development of new renewable energy projects as well as negative environmental issues, we believe that policy makers may consider the development of future power plants based on coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment. These actions may be addressed in order to improve security levels for the country's energy resource and electricity generation systems.

5.1.8.2 Colombia's electricity generation system

Colombia's electricity generation system was unbundled horizontally in order to promote competitiveness through private participation. After deregulation part of the system's infrastructure was sold from the states' owned enterprises. Currently there are 66 different private participants which own 60% of the installed capacities, while government owns 40%. Although government has decreased its participation in the system, it still has large participation in electricity production because its core technologies are hydro power plants which operate permanently as base plants. The State has market participation in the power market superior to 50%. The electricity generation system has an installed power capacity at the year 2011 of 14.42 GW. Colombia's power plants technologies are based 71% on hydro power, 28% thermal power (gas, coal, and oil derivate), and 1% in wind and solar.

The development of new power plants growth has registered an average annual growth of 3.25% during the period under study. Domestic production of electricity at the year 2011 reached 58.63 TWh while consumption represented 57.16 TWh, and for the foregoing reasons, the country is a net exporter of electricity for neighboring countries such as Venezuela and Ecuador. The country is intended to develop new power plants based on stable energy commodities in terms of its production in order to improve its energy mix and secure supplies of energy resources to produce electricity. The infrastructure efficiency as well as natural phenomena is the main factors affecting the overall performance this system. Figure 5.30 presents Colombia's Electricity Generation System Security of Supply Performance.

Figure 5.30 Colombia's GSSSI

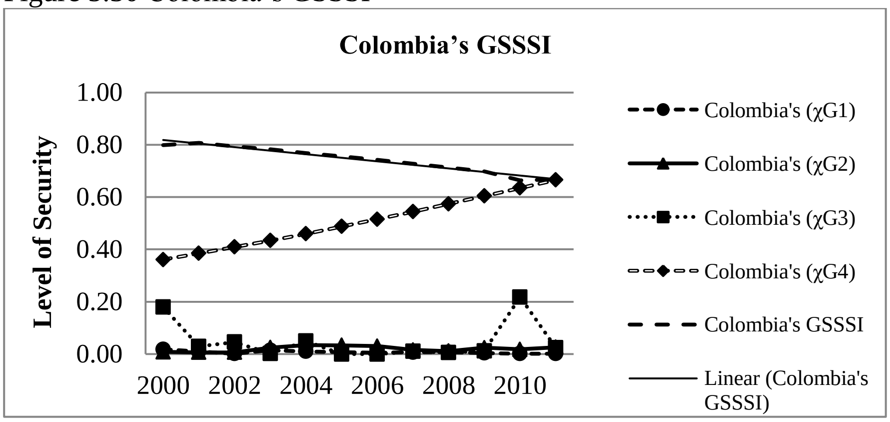


Figure 5.30 presents the performance of the indicators that compose Colombia's electricity generation system security of supply index (GS). In one hand, the particular nature of the system, which is mainly based on hydro power technologies and resources, has allowed the industry to have an acceptable performance for the indicators $\chi G1$, $\chi G2$, and $\chi G3$. Colombia has joined acceptable levels of installed capacities, reserves, and the country has been a net exporter of electricity to Ecuador. However, it was noticed that the performance of the indicator $\chi G4$ has decreased over the time and it is consistent with the power plants' ages, and it is growing steadily. It seems that the dynamic variations occurred along the period under study for the referred indicators were as a consequence of natural phenomena issues as well as inefficiencies of the performance of the electricity industry's downstream systems (electricity transmission and distribution systems).

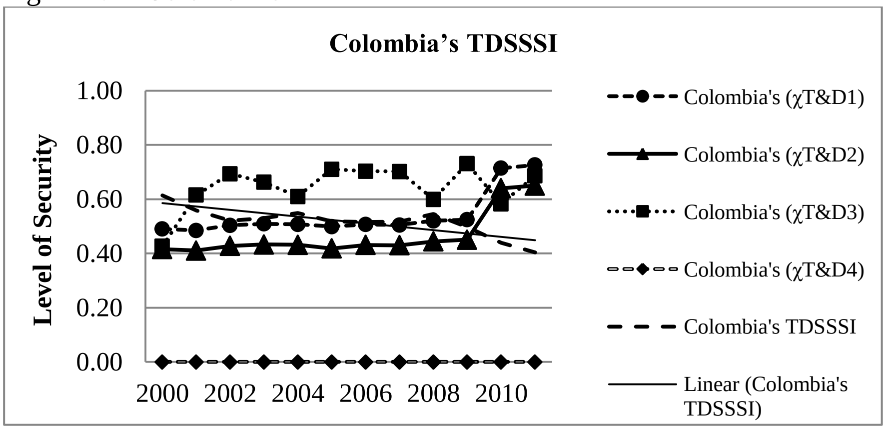
The reduction in Colombia's GS index goes along mainly with the negative effects carried out by the power plants' ages because the performance of the other indicators have been either acceptable or the optimal. However, it is importance to mention that as the indicator $\chi G4$ is growing progressively in the same way security of electricity supply on the overall electricity generation system tends to decrease. The performance of the country's GS index has decreased from 80% in the year 2000 to 67% in 2011. The system decreased its performance from a high low level of security of supply to a medium high level. We considered that this variation during the period under study has been high and faster. For the foregoing reasons, further investments in infrastructure additions, upgradings, as well as timely maintenances are required in order to keep or increase the security and continuity of electricity supply. Also, in order to secure both the energy resources and the electricity generation systems policy makers may consider the development of future power plants based on coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment.

5.1.8.3 Colombia's electricity T&D systems

Colombia's electricity transmission and distribution systems are owned and operated by both State and private participants. In electricity transmission the government is the largest participant, while in electricity transmission is the private sector, but State still has strong participation in important regions. In these systems, private participation has been allowed and unbundling was implemented through regionalization. The systems have an installed capacity at the year 2011 of 24,792 kilometers in power lines. Infrastructure development has growth at 2.58% in average per annum, while electricity demand has growth at 2.83% in average per annum due to the country's economic growth. The margins between infrastructure development and demand's growth do not allow the systems to count with enough reserves and operate out of technical limits based on standards.

Total electricity coverage in Colombia is 96.8% (2011), being almost 99.9% in urban areas and around 86.7% in rural ones. The average number of interruptions annually per customer is around 13, while its duration is around 5.10 minutes in urban areas. Electricity prices are stable under market mechanisms in the electricity generation system and during 2011 they were in average US $ 0.1745 per kWh, however, these are still subsidized through governmental policies. The main challenges for both systems are natural phenomena and demand's growth. The last one is as a consequence of the country's economic prosperity registered during the past decade and it is requesting the development of a tougher infrastructure that responds to demand's requirements on time as well as works under technical standards to improve efficiency and security of supply. Figure 5.31 shows Colombia's electricity transmission and distribution systems security of supply performance.

Figure 5.31 Colombia's TDSSSI



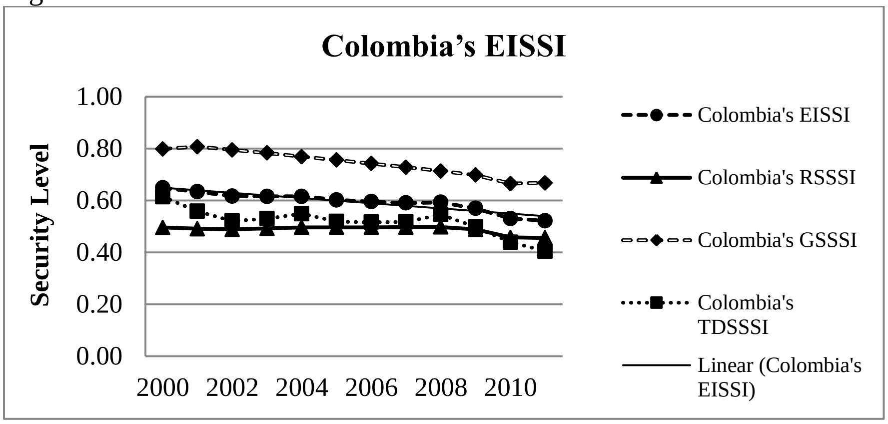
The Figure 5.31 shows that Colombia's electricity transmission and distribution systems security of supply index (T&DS) has decreased considerably over the time. The indicators χT&D1, χT&D2, and χT&D3, have decreased its performance. The track denotes that electricity demand growth has been the main cause for reducing the systems performance. As we have seen most of the problems regarding security of supply are located in the electricity distribution system since the country has a strong infrastructure in its electricity transmission system. The overexertion of electrical infrastructure has carried out heat over itself and the increase of technical losses as well as the reduction of the power factor performance in accordance with standards. However, the power factor in general (χT&D4) does not reflect its low performance in the electricity distribution system since it has been compensated with the high performance of the electricity transmission system. The level of losses is dynamic and it has been as a result that follows mostly to non-technical factors such as electricity theft.

Security of electricity supply has decreased along the period under study for around 21%, and it has been as a consequence of infrastructure overexertion, production of heat in the electrical infrastructure, and increased level of non-technical losses which behavior has been dynamic. Security of supply has decreased from 61% in 2000 to 40% in 2011. This variation is high and fast taking into account that it occurs in twelve years. As a matter of fact, we have seen that the relationships exist since the reserves capacities levels were the indicator of the most dynamic performance in the electricity generation system and it also has motivated to continue importing electricity. These issues have affected negatively security of the electricity generation system.

5.1.8.4 Colombia’s electricity industry security of supply index

Colombia’s EISSI has shown that the performance of the industry is strictly attached to the resource system outcomes as well as the infrastructure efficiency. The country’s electricity industry has a medium level of security of supply. This situation is as a consequence of the fluctuations in the production of the renewable energy resources as well as the efficiencies of electrical infrastructures of the electricity generation and distribution systems. Colombia is vulnerable to the natural phenomena of El Niño and La Niña, which affects the production of water and biomasses. The electricity generation system faced the influences of storms, floods, droughts, and extreme temperatures, which reduced the accumulation of the necessary levels of water in the power plants' dams. The reduction in the performance of all the systems carried out the overall EISSI's low output. However, some achieved improvements in the electricity transmission system have reduced the negative impacts of the other systems in reducing the EISSI's output. Figure 5.32 shows Colombia's electricity industry security of supply performance.

Figure 5.32 Colombia's EISSI



Based on the analysis of Figure 5.32 we can figure out that Colombia's EISSI has decreased from 65% in the year 2000 to 52% in 2011. We have seen that security level has decreased normally, since it contracted 13%, same as in the case of Mexico, during the period under study. As a matter of fact, the main causes in decreasing Colombia's EISSI have been instability in the production of renewable energy resources due to environmental issues. This last factor also has increased the accomplishment of some changes in the energy mix. The country became dependent and importer of fossil fuels in order to compensate those negative variations in the production of renewable energy resources and electricity. The electricity distribution system tends to operate out of the established parameters by technical standards because of electricity demand's growth under the basis of an economic boom that the nation has been facing.

Colombia's electricity industry has decreased the level of security of supply (EISSI) in all the systems that compose its electricity industry. Inefficiencies of the downstream systems will enhance more wastefulness in the upstream systems. The electricity distribution infrastructures need to be fortifying by means of automation and increase power lines coverage. These actions are required in order to mitigate congestion and overexertion problems, and it can be through building parallel lines, increasing voltage levels or the development of distributed generation systems closer to demand. Colombia's policy makers can focus on the development of future power plants with coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment. By these means the nation can access other kinds of energy resources as well as increasing power generation capacities. Coal can be a solution since Colombia is wealthy regarding this commodity. Finally, the national electricity industry needs to operate under well recognized standards in order to keep an optimal level of security of supply.

5.1.9 Ecuador's electricity industry

5.1.9.1 Ecuador's energy resources system

Ecuador is a net exporter of hydrocarbons without processing. This situation has affected negatively by reducing its proven reserves of fossil fuels. However, the country has accomplished new discoveries and additions during the period under study. Ecuador has strong potential to produce electricity and be self-sufficient based on hydro energy as well as biomasses. However, the natural phenomena of El Niño and La Niña have been affecting negatively the production of renewable energy resources through the employment of fossil fuel resources in its energy mix, which are increasing in terms of concentration due to its utilization. During the past 12 years the country has reduced its energy mix from renewable energy resources, especially from hydro power, and became a net importer of natural gas as well as other type of commodities derived from crude oil. This nation has experienced price fluctuations in importing these energy commodities because its prices have been linked to oil prices. Figure 5.33 shows Ecuador energy resources system security of supply performance.

Figure 5.33 Ecuador’s RSSSI

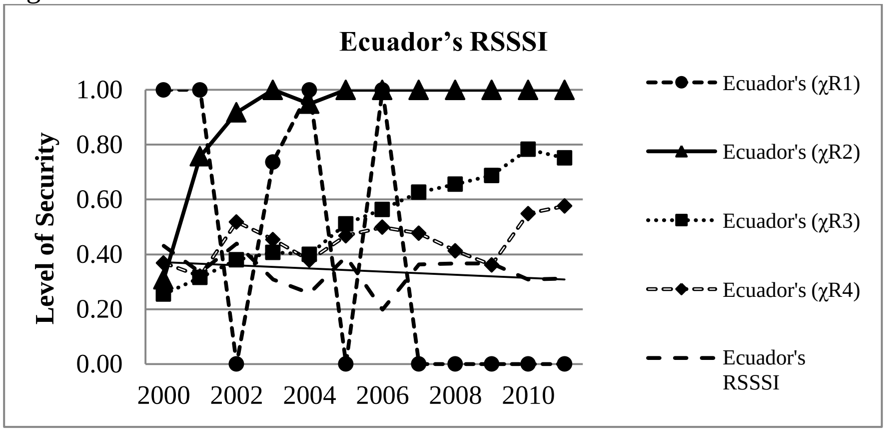


Figure 5.33 shows the performance of the indicators that compose Ecuador electricity generation system security of supply index (RS). The observed behavior of the indicators χR2, χR3, and χR4 means that they are either over or closer to 1. This situation reflects a low performance of these indicators and jeopardizes the entire system. Also, in order to improve the performance of χR1 this nation undertook exploration activities in order to add new reserves of fossil fuels for its stocks. However, Ecuador has reduced the performance of its RS index as a consequence of modifying its energy mix based on hydro power to produce electricity based on crude oil as well as natural gas. The nation became a net importer of fossil fuels for producing electricity and has suffered price fluctuations. These elements affected the overall performance of the RS index in terms of security of supply.

The country’s RS retracted its performance from 43% in the year 2000 to 31% in 2011. We considered that this variation during the period under study is normal. The path of Ecuador RS index has decreased from a medium level to a low high level of security of supply. The main reasons have been the modifications accomplished in its energy which triggered the country to import fossil fuels permanently for producing electricity and it has suffered price fluctuations. Policy makers can adopt several procedures for the development of future power plants the adoption of coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment.

These actions are in order to stimulate a positive impact on the level of security of supply for overall electricity industry. By these means the nation can access other kinds of energy resources as well as increase power generation capacities. For Ecuador the same as Panama, we believe that coal energy resources can be a solution since Colombia is the one of the largest suppliers in Latin America and it is their neighboring nation, and at the same time reducing freight costs.

5.1.9.2 Ecuador's electricity generation system

Ecuador electricity generation system is constituted as a vertical monopolist with a limited private participation through the business model of independent power producers (IPPs). This is the only form of private participation in this system since the Electricity Corporation of Ecuador (CELEC) is the large state owned enterprise in charge of the system. The electricity generation system has an installed power capacity at the year 2011 of 5.09 GW. Ecuador power plants technologies are based 49% on hydroelectricity, 36% on crude oil commodities, 12% on natural gas, and 3% solar and wind power. The development of new power plants growth has registered an average annual growth of 5.23% during the period under study.

The infrastructures' ages as well as the core energy resources and technologies employed to produce electricity are the main factors affecting the overall performance of Ecuador electricity generation system. Additionally, external factors such as natural phenomena affect hydroelectricity production. Figure 5.34 presents Ecuador Electricity Generation System Security of Supply Performance.

Figure 5.34 Ecuador's GSSSI

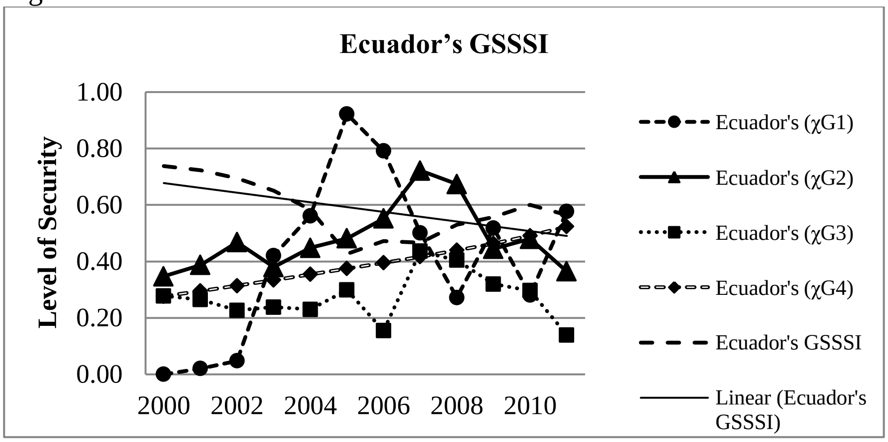


Figure 5.34 presents the performance of the indicators that compose Ecuador electricity generation system security of supply index (GS). In one hand, the observed behavior of the indicators χG2 and χG3 means that they are getting far from 1. This situation reflects an improvement in the performance of these indicators and a reduction of risks for the entire system. On the other hand, the nature of χG1 seems to be more dynamic than the other indicators and it obeys to the fact that it is linked to electricity demand's growth as we have argued before. However,

the tendency of the performance of this indicator has been to decrease its performance during the period under study. In addition, the equipment's ages which is represented by χG4 has reduced the performance along the time in a progressive way. We believe that the reduction in the performance of χG1 and χG4 has been the determinant factor for reducing the electricity generation system's overall level of security of supply.

Ecuador has been importing electricity and the traded volumes have been significant, since the country has not been able to respond to demand's requirements through installing enough capacities to cover domestic consumption of electricity. Compared with Mexico this country has not been self-sufficient in terms of electricity production. Furthermore, the performance of the country's GS index has decreased from 74% in the year 2000 to 56% in 2011, which has been a strong variation and faster. It has been as a consequence of the reduction in the performance of effective installed capacities, electricity imports as well as the power plants' ages. Ecuador's GS index is in a medium level of security of supply.

5.1.9.3 Ecuador's electricity T&D systems

Compañía Nacional de Transmisión Eléctrica (TRANSELECTRIC) is in charge of operating the electricity transmission system, while there are 13 national electricity distribution companies which operate regionally. In these systems, private participation is not allowed and it operates under the basis of a pure state monopolistic model. The systems have an installed capacity at the year 2011 of 3,655 kilometers in power lines, while 8,517 MWA in transformer capacities.

Infrastructure development has growth at 3.85% in average per annum, while electricity demand has growth at 7.08% in average per annum. The margins between infrastructure development and demand's growth are considerable. Infrastructure overexertion is increasing and the tendency for both systems is operating out of technical limits remained on standards.

The level of losses represents almost 20% of total production of domestic electricity. Total electricity coverage in Ecuador is 95.5% (2011), being 98.4% in urban areas and around 89.9% in rural ones. The average number of interruptions annually per customer is around 11, while its duration is around 7.93 minutes. Electricity prices are highly subsidized, especially for residential customers, and at the year 2011 these were in average US $ 0.0799 per kWh. The main challenges for both systems are the development of a tougher infrastructure that responds to demand's requirements on time as well as works under technical standards to improve efficiency and security of supply. Figure 5.35 shows Ecuador electricity transmission and distribution systems security of supply performance.

Figure 5.35 Ecuador's TDSSSI

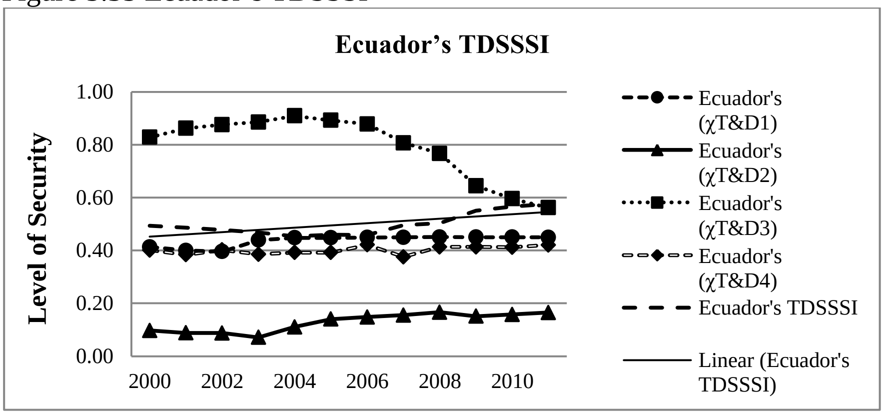


Figure 5.35 illustrates the performance of the indicators that compose Ecuador electricity transmission and distribution systems security of supply index (T&DS). The observed behavior of the indicators χT&D1 and χT&D2 is increasing in a reasonable way the utilization factor of electrical infrastructure associated with transformers and power lines. It obeys to electricity demand's growth but it has been minimized because the systems have strong infrastructure. Ecuador has developed a strong infrastructure for these systems as a consequence that its electricity industry is permanently and highly dependent on electricity imports from Colombia. The level of risks for these indicators is under acceptable parameters according to technical standards. The development of such strong infrastructure has influenced positively the performance of the indicators χT&D3 and χT&D4. The reduction in the level of losses has been considerable and the power factor is also under acceptable parameters according to technical standards and free of threats. The systems were favored as a consequence of automation of substations and the implementation of optical fiber in the grids as part of the bi-national electrical interconnection Ecuador-Colombia.

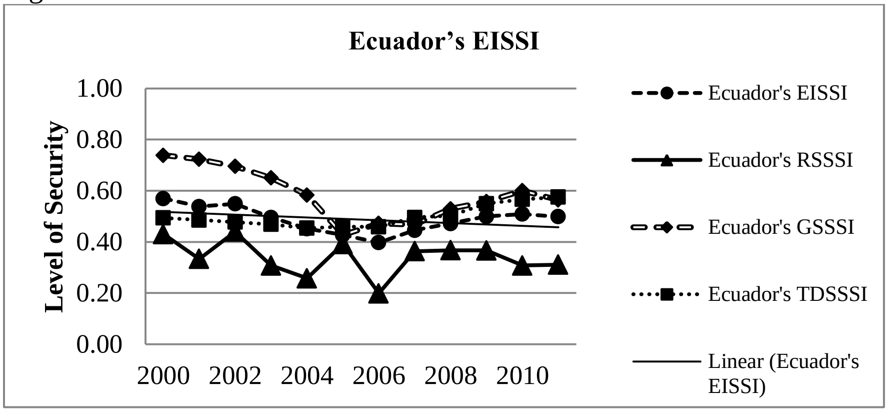
Ecuador T&DS index has increased 9%, same level as Panama, for both systems during the period under study. The country's T&DS index moved positively from 49% in the year 2000 to 58% in 2011, which is a medium level of security of electricity supply for the entire system. We considered that this variation has been reasonable and the undertaken activities have played a significant role in increasing the level of security of supply in the overall systems due to technical losses which are represented by the indicator χT&D3 the ones which have shown a positive and fast performance. The level of risk regarding technical and non-technical losses decreased during the period under study from 83% in the year 2000 to 56% in 2011.

5.1.9.4 Ecuador's electricity industry security of supply index

Ecuador EISSI has shown that the performance of the industry is strictly attached to the resource system outcomes as well as the electrical infrastructure efficiency. The country's electricity industry has a medium level of security of supply. This situation is as consequence that both energy resources as well as electricity generation systems decayed in its performance. The negative effects of demand's growth, which has been faster than the development of new energy projects, as well as the negative effects of the natural phenomena El Niño and La Niña have also played a vital role in reducing the electricity industry's overall security of supply performance.

Although the electricity transmission and distribution systems increased their level of security of supply the results have not been enough to support the overall electricity industry security of supply index performance. The reduction of Ecuador EISSI has been as a consequence of the upstream industry's systems. Figure 5.36 shows Ecuador electricity industry security of supply performance.

Figure 5.36 Ecuador’s EISSI



Based on the analysis of Figure 5.36 we can set that Ecuador EISSI has decreased from 57% in the year 2000 to 50% in 2011. We have seen that security level has decreased in a measurable way, since it diminished 7% during the period under study. As a matter of fact, the main causes in decreasing the country’s EISSI have been the negative effects of demand’s growth, which has been faster than the development of new energy projects, as well as the negative environmental issues. These factors have also improved the development of new power plants based on fossil fuel resources and changing the country’s energy mix for producing electricity. Furthermore, these situations have made the Ecuador a net importer of hydrocarbon resources and electricity over the time. Ecuador ‘s electricity industry is limited to offer reserves capacities based on electricity imports and supported by the efficiencies of the electricity transmission and distribution systems these matters.

Ecuador electricity industry has been affected mainly by issues located on the electricity industry’s upstream systems, which are susceptible to demand’s growth effects as well as natural phenomena issues. The industry has not been effective in increasing electrical infrastructure capacities as well as diversifying its energy mix for producing electricity. The developments of new energy projects have not been at the same rhythm as the demand's growth. Policy makers can concentrate on these issues for the development of future power plants the adoption of coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment. These actions are in order to stimulate a positive impact on the level of security of supply for overall electricity industry. By these means the nation can access other kinds of energy resources as well as increase power generation capacities. Coal can be a solution since Colombia is the one of the largest suppliers in Latin America and is closer to Ecuador and it can contribute in reducing freight costs.

5.2.10 Peru's electricity industry

5.1.10.1 Peru's energy resources system

Peru is a net exporter of hydrocarbons, without processing or transformation, which has also impacted negatively by reducing its proven reserves of fossil fuels. However the country has implemented accurate policies and a business model in which private participants are in charge of exploration and development of hydrocarbon resources. The country has been able to accomplish new discoveries and additions during the period under study and has shown a dynamic performance in this regard. Based on the nation's geological and environmental conditions, Peru has a strong potential to produce electricity and be self-sufficient based on hydro energy as well as biomasses. As a matter of fact, this nation has been doing the best use of its domestic renewable energy resources to produce electricity and cover the electricity demand's growth consumption. The country's energy mix to produce electricity is based on around 56% on hydro power and this nation has also the potential to be a net exporter of electricity to neighboring countries.

Additionally, since many Latin American countries with hydro power potential as in the case of this nation are facing social resistance for the construction of hydropower plants as well as negative environmental effects. The natural phenomena of El Niño and La Niña are a common problem for this nation that has access to the Pacific Ocean from the Latin American region. Peru is not smelting the same proportions of glacier ice to produce water that is employed in hydroelectric power plants. Peru intends to mitigate the negative effects generated by these environmental issues on the production of renewable energy resources through the employment of fossil fuel resources in its energy mix. In terms of coal, the country is self-sufficient but indigenous resources have not been developed to be employed in the electricity industry. In terms of resources' availability, Peru is importing fossil fuels. Figure 5.37 shows Peru's energy resources system security of supply performance.

Figure 5.37 Peru’s RSSSI

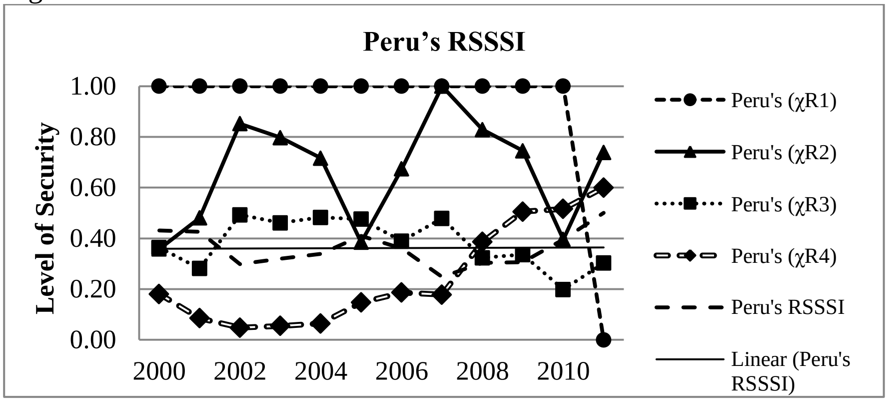


Figure 5.37 shows the performance of the indicators that compose Peru energy resources system security of supply index (RS). In one hand, Peru is not a world’s leader producing crude oil and as a consequence its proven reserves indicator χR1 tends to be placed inside the risky levels while new and considerable discoveries are accomplished in order to increase the level of proven reserves and surpass the constraint of production levels. On the other hand, because of natural phenomenon issues, the country tends to reduce periodically the domestic production of renewable energy resources and it also has affected negatively the performance of the indicators χR2, χR3, and χR4. We can see that once Peru increases its proven reserves of energy resources it starts to decrease energy imports and mitigate the negative effects of price fluctuations on fossil fuels. As a matter of fact, Peru’s RS index has improved its performance.

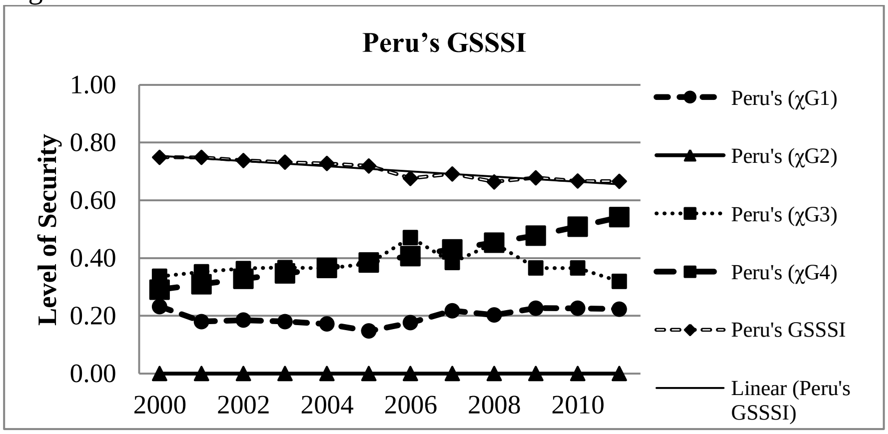
The performance of Peru’s RS index has increased from 43% in the year 2000 to 50% in 2011. The index is decreasing and it means that the level of security of supply of the energy resources system is getting lower. We considered that this variation during the period under study has not been significant along the period under study but it has been positive for the performance of the overall system. The positive impacts came into the light through modifying the electricity industry's energy mix and increase the dependency on imports of fossil fuel resources although they are subjected to price fluctuations.

5.1.10.2 Peru's electricity generation system

Peru's electricity generation system was unbundled horizontally in order to promote competitiveness through private participation. After deregulation part of the system's infrastructure and other expansions around the states owned enterprises were sold. Currently there are 10 different private participants that own 64% of the installed capacities, while government owns 36%. Although the government has decreased its participation in the system, it still has large participation in electricity production because its core technologies are hydro power plants which operate permanently as base plants. Moreover, the State has market participation in the power market superior to 40%. The electricity generation system has an installed power capacity at the year 2011 of 8.56 GW.

Peru's power plants technologies are determined by 56% on hydro power, 42% on thermal power (gas, oil derivate, and coal), and 2% on wind and solar powers. The development of new power plants growth has registered an average annual growth of 3.25% during the period under study. Peru is seeking to develop new power plants based on stable energy commodities in terms of its production in order to improve its energy mix and secure supplies of energy resources to produce electricity. The infrastructure efficiency as well as natural phenomena is the main factors affecting the overall performance of this system. Figure 5.38 presents Peru’s Electricity Generation System Security of Supply Performance.

Figure 5.38 Peru’s GSSSI



The performance of the overall system has decreased 8% in terms of security of supply along the period under study. Figure 5.38 presents the performance of the indicators that constitute Peru’s electricity generation system security of supply index (GS). On one hand, the peculiar nature of the system, which is mainly based on hydro power technologies and resources, has allowed the industry to have an acceptable performance for the indicators χG1, χG2, and χG3. It was noticed that among all the indicators the reserves capacities’ behavior (χG3) has been the most dynamic and it obeys to the variations in water production and inefficiencies in the electricity’s industry downstream systems (electricity transmission and distribution systems). It was noticed that the performance of the indicator $\chi G4$ has decreased over the time and it corresponds to the power plants' ages, which is growing steadily. This has been the most influential indicator reducing the performance of the overall system.

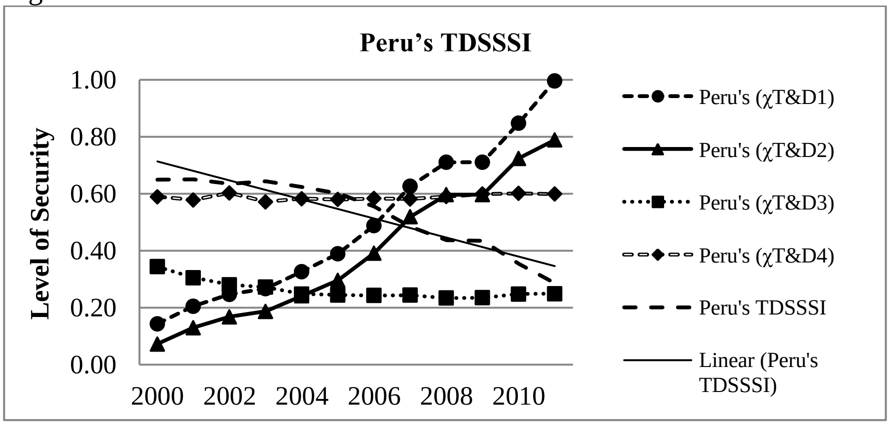
The decline in Peru's GS index follows mainly the negative effects carried out by the power plants' ages, since the performance of other indicators has been stable. However, it is important to mention that as the indicator $\chi G4$ is growing progressively in the same way security of supply of the overall electricity generation system tends to decrease. The performance of the country's GS index has decreased from 75% in the year 2000 to 67% in 2011. The system decreased its performance from a high-low level of security of supply to a medium high level. We considered that this variation during the period under study has been moderated.

5.1.10.3 Peru's electricity T&D systems

Peru's electricity transmission and distribution systems are owned and operated by both State and private participants. In electricity transmission the government is the largest participant, while in electricity transmission is the private sector. In these systems private participation has been allowed and unbundling was implemented through regionalization. The systems have an installed capacity at the year 2011 of 18,636 kilometers in power lines. Infrastructure development has growth at 2.66% in average per annum, while electricity demand has growth at 6.72% in average per annum due to the country's economic growth. The margins between infrastructure development and demand's growth do not allow the systems to count with enough reserves and operate out of technical limits settled on standards.

The average number of interruptions annually per customer is around 14.5, while its duration is around 12.94 minutes. Total electricity coverage in Peru is 98.5% (2010), being 99.4% in urban areas and around 96.8% in rural ones. Electricity prices are subsidized through fiscal resources and at year 2011 the price was in average US $ 0.0873 per kWh. The main challenges for both systems are natural phenomena and demand's growth. The last one is as a consequence of the country's economic prosperity registered during the past decade and it is requesting the development of a tougher infrastructure that responds to demand's requirements on time as well as works under technical standards to improve efficiency and security of supply. Figure 5.39 shows Peru's electricity transmission and distribution systems security of supply performance.

Figure 5.39 Peru's TDSSSI



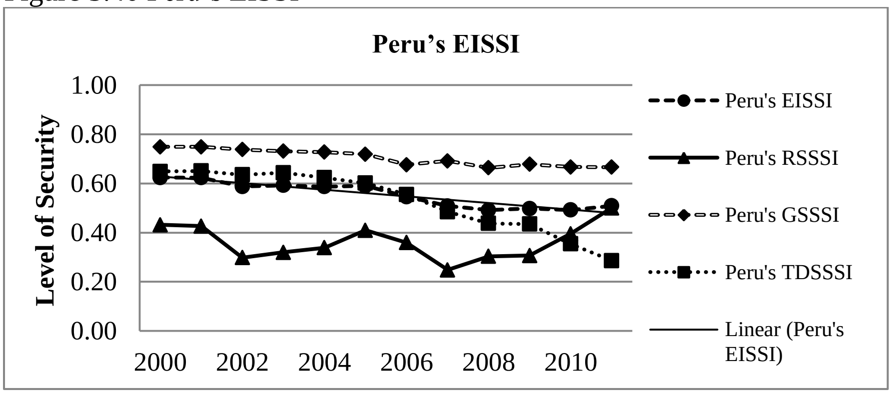
The Figure 5.39 presents Peru's electricity transmission and distribution systems security of supply index (T&DS), which has decreased considerably over the time. The indicators χT&D1 and χT&D2 have decreased its performance gradually. The track denotes that electricity demand's growth has been affecting infrastructures capacities. Electrical infrastructure overexertion is the main cause for reducing the systems' performance. These situations have been as a consequence of demand's growth, which also follows the economic boom that this country has been facing. As we have seen the indicators χT&D3 and χT&D4 have an acceptable behavior since they have kept either the same path or increased its performance. Both technical losses and power factors have shown that they are not the reason in decreasing the level of security of supply for the overall electricity transmission and distribution systems. By failing to comply with standards in certain activities of a system, the risk of failures increased. Later on, it will increase the possibility of interruptions in supplying the electricity service to end consumers.

Security of supply has decreased from 61% in 2000 to 40% in 2011. The performance decreased around 36%, which has been a high and fast movement taking into account that it happened during a period of time of twelve years. This is the most dramatic case in reducing its level of security for these systems, followed by Colombia and Argentina. The economic growth that Peru has been facing has enhanced the electricity demand's consumption, which has carried out electrical infrastructure overexertion and this has reduced the overall level of security of supply for both systems.

5.1.10.4 Peru’s electricity industry security of supply index

Peru’s has a medium level of security of supply in its electricity industry due to the accomplished improvements in the energy resources systems which have secured the supply of energy commodities employed in electricity production. However, the performance of the Peruvian electricity industry has decreased in terms of security of supply over the time. These situations have been as a consequence of the contraction in the performance of the electricity generation as well as the electricity transmission and distribution systems. Inefficiencies in the performance of electrical infrastructure due to equipment’s ages as well as overexertion have reduced the level of security of supply for the overall electricity industry. External factors have affected the Peruvian electricity industry such as environmental and economic factors. This nation is vulnerable to natural phenomena in addition during the period under study; the country has faced economic growth in a progressive way. Figure 5.40 shows Peru’s electricity industry security of supply performance.

Figure 5.40 Peru’s EISSI



Based on the analysis of Figure 5.40 we can presume that Peru’s EISSI has decreased, but quietly, from 62% in the year 2000 to 5% in 2011. We have seen that security level has decreased in a measured way, since it contracted 11%, same as in the cases of Mexico and Colombia, during the period under study. As a matter of fact, the main causes in decreasing Peru’s EISSI have been the contraction in the performance of the electricity generation system as well as the electricity transmission and distribution systems. In the case of electricity generation system the most influential factor has been the power plants’ ages which have been growing steadily and in the near future this system will require the development of new projects or upgradings. Regarding the electricity transmission and distribution systems infrastructure overexertion has been the main cause for declining the performance of those systems.

It has been as a consequence of the economic boom which the country has been living that has also affected the electricity demand’s growth. It was noticed that reserves capacities in the electricity generation system had a dynamic behavior and follow the variations in water production since it is a natural phenomenon and inefficiencies in the electricity’s industry downstream systems (electricity transmission and distribution systems). Peru’s electricity transmission and distribution require the development of stronger electrical infrastructure by means of automation and increase power lines coverage. These actions are required in order to mitigate congestion and overexertion problems, and it can be through building parallel lines, increasing voltage levels or developing distributed generation systems closer to demand. In order to secure both the energy resources and the electricity generation systems policy makers may consider the development of future power plants based on coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment.

5.1.11 Chile’s electricity industry

5.1.11.1 Chile’s energy resources system

Chile produces hydrocarbons which are processed or transformed, and these activities have influenced negatively by reducing its proven reserves of fossil fuels. Despite of this wealth, the country is not a self-sufficient to cover domestic demand and thus the country is a net importer of these types of energy commodities. The country has been able to accomplish new discoveries and additions during the period under study. Chile has applied accurate policies in order to supply domestically as much as possible the necessary energy resources that its electricity industry employs in producing electricity.

This nation is also vulnerable to natural phenomena which tend to decrease production of renewable energy resources. The country has a well-balanced energy mix to produce electricity in comparison with all other Latin American countries analyzed in this research. Chile has been doing the best use of its available resources as the case of hydro power and coal, which are contributing in diversifying the nation’s energy mix to produce electricity. Figure 5.41 shows Chile’s energy resources system security of supply performance.

Figure 5.41 Chile’s RSSSI

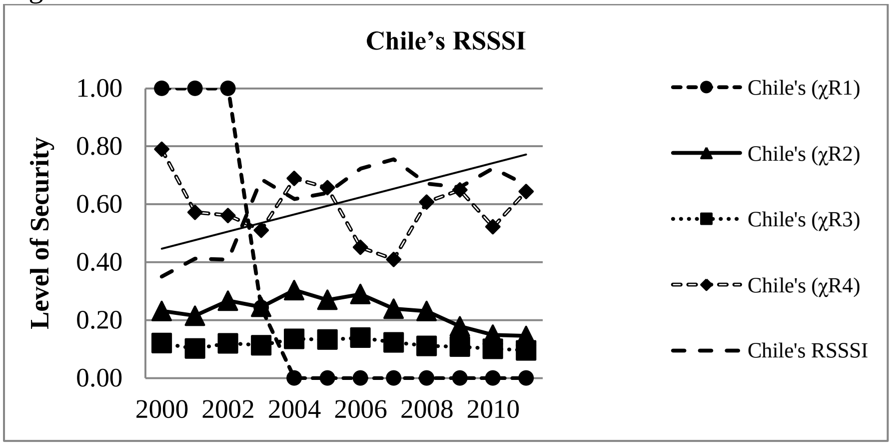


Figure 5.41 shows the performance of the indicators that compose Chile’s energy resources system security of supply index (RS). The country has been able to accomplish new discoveries and additions during the period under study for these reasons; the performance of χR1 has improved. Although this nation is a net importer of energy resources, its policy makers have minimized risks and controlled price’s fluctuation through reducing levels of imports, diversifying and selecting less risky energy resources suppliers as well as diversifying the electricity industry’s energy mix.

This country is employing mainly hydro power and coal energy resources for producing electricity although there is a sort of dependency on other kind of fossil fuels, which are used in order to compensate negative environmental issues. The performance of the indicators χR2, χR3 and χR4 has improved positively in terms of security of supply over the time. Guatemala, El Salvador, and Peru were the countries that improved security of supply in their energy resources system, but the case of Chiles in comparison with those countries is the best case since the reached level of security of supply has been significant.

Chile has applied policies positively that contributed to improve the performance of its energy resources system in terms of security of supply. During the period under study, where price fluctuations in fossil fuels have been present every day in the international markets, the performance of Chile’s energy resource system index (GS) has increased its level of security of supply from 35% in the year 2000 to 67% in 2011 as it was seen in the figure above. We considered that this variation during the period under study has been high and fast since the growth was for around 32%. Furthermore, this dramatic variation has been a result of the positive ‘chain effect’ due to policy decisions in selecting less risky energy resources suppliers as well as diversifying the electricity industry’s energy mix.

5.1.11.2 Chile’s electricity generation system

Chile’s electricity generation system was privatized by complete in order to promote competitiveness through private participation. In this case the assets of the largest state owned enterprise, Empresa Nacional de Electricidad (ENDESA), were sold in 1989. Currently in Chile, there are 5 entities which own 86% of the total installed capacities and operate power plants with capacities over 3 MW. On the other hand, there is a group of small producers of electricity which own 14% of the total installed capacities and with capacities below 3 MW. ENDESA is owned by ENERSIS and it remains as the largest electric utility company in Chile with a market share of 35% as a result to that most of its facilities is hydro power plants. The electricity generation system has an installed power capacity at the year 2011 of 17.83 GW.

At the year 2011 Chile was 60% dependent on thermal power, 36% on hydro power, and 4% on other kind of renewable energies. The development of new power plants growth has registered an average annual growth of 5.55% during the period under study. Domestic production of electricity at the year 2011 reached 54.10 TWh while consumption represented 54.83 TWh, and for the preceding reasons the country is performing as a net importer of electricity because its electricity industry imported 0.73 TWh from Argentina. Chile needs to continue developing new power plants in order to meet demand’s requirements. The infrastructure efficiency as well as natural phenomena is the main factors affecting the overall performance this system. Figure 5.42 presents Chile’s Electricity Generation System Security of Supply Performance.

Figure 5.42 Chile’s GSSSI

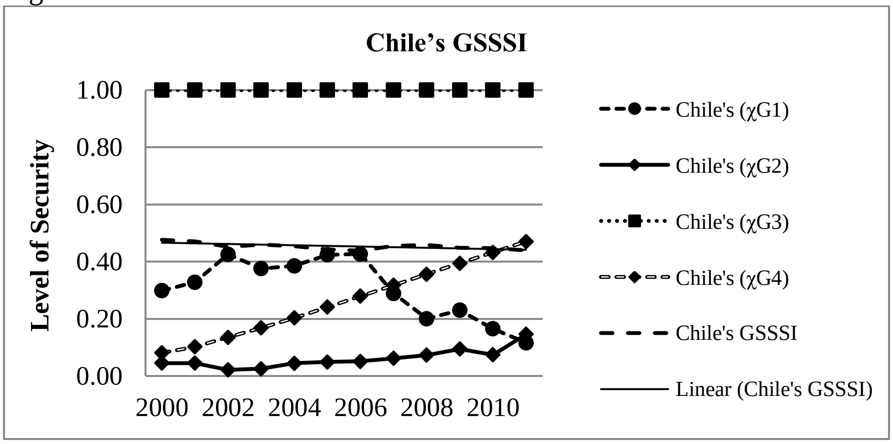


Figure 5.42 shows the performance of the indicators that compose Chile's electricity generation system security of supply index (GS). The observed behavior of the indicators χG2, χG3, and χG4 is that all of them are increasing towards 1. This situation reflects a reduction increase of risks in the overall level of security for the GS index. However it is possible to see that the performance of χG1 has improved and it has been by means of adding new installed capacities, upgradings or accomplishing maintenances on time in the core equipment of power plants. These actions probably have favored the behavior of χG2 which has been stable during the period under study. Additionally, they may be the reason of the low performance of χG3, which is out of an optimal level because it is susceptible to be affected by electricity demand's growth as well as the equipment ages (χG4), which is increasing steadily.

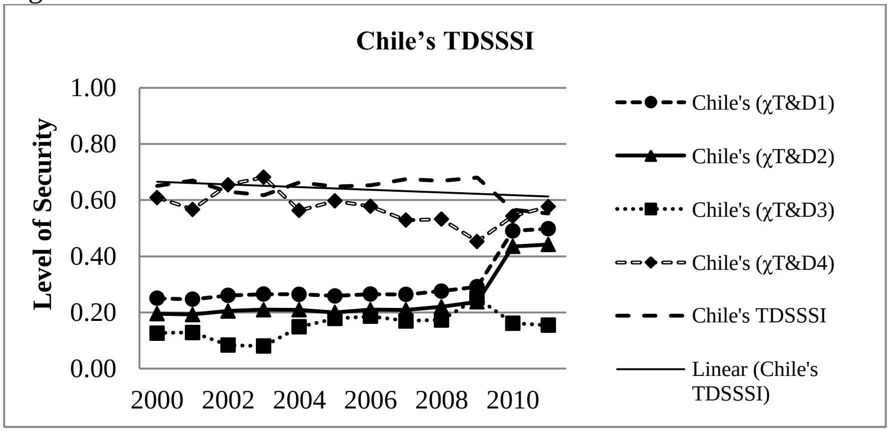
The performance of the Chile's GS index has decreased from 48% in the year 2000 to 44% in 2011. The index is decreasing towards 0 which means that the level of security of supply on the generation system is getting lower. We considered that this variation during the period under study has been measured and it has been as a consequence of the nature of the generation infrastructure itself as well as its age. If new additions of installed capacities are not accomplished in the coming years the country may not be able to respond demand's requirements by itself and also can increase its dependency on electricity imports.

5.1.11.3 Chile’s electricity T&D systems

Chile’s electricity transmission and distribution systems are owned and operated in conjunction by five different private entities. These companies are distributed in four different geographical regions. There are two Centers of Economic Load Dispatch (CDECs), which operate as a sort of regional wholesale electricity markets. The systems have an installed capacity at the year 2011 of 13,214 kilometers in power lines, while 52,789 MWA in transformer capacities. Infrastructure development has growth at 3.26% in average per annum, while electricity demand has growth at 4.66% in average per annum. The margins between infrastructure development and demand’s growth do not allow the systems to count with enough reserves and operate out of technical limits settled on standards.

Total electricity coverage in Chile is 98.9% (2011), being almost 99.6% in urban areas and around 94.1% in rural ones. The average number of interruptions annually per customer is around 8, while its duration is around 2.39 minutes in urban areas. Electricity price is settled under market mechanisms in the electricity generation system and at the year 2011 it was in average US $ 0.186 per kWh. The main challenges for both systems are the development of a stronger infrastructure that responds to demand’s requirements on time as well as works under technical standards to improve efficiency and security of supply. Figure 5.43 shows Chile’s electricity transmission and distribution systems security of supply performance.

Figure 5.43 Chile’s TDSSSI



The Figure 5.43 shows that Chile’s electricity transmission and distribution systems security of supply index (T&DS) has decreased over the time. The indicators χT&D1, χT&D2, χT&D3, and χT&D4 have decreased softly their performance. The track denotes that electricity demand growth has been the main cause in reducing the systems performance. As we have seen, most of the problems regarding security of supply are located in the electricity distribution system since the country has a robust infrastructure of its electricity transmission system. The overexertion of electrical infrastructure has carried out heat over itself and increase of technical losses as well as the reduction of the power factor performance. The technical losses as well as the power factor negative effects have been stabilized with the support of automation in substations as well as installing optical fiber in the electricity transmission system as part of the international electrical interconnection with Argentina.

For both systems security has been decreased during the period under study for around 10%, and this has been as a consequence of infrastructure overexertion, production of heat in the electrical infrastructure, and increased technical losses. Security of supply has decreased from 65% in 2000 to 55% in 2011. For the electricity distribution system equipment, installed capacities have not been growing at the same level as the demand's requirements. What is important to consider, is the fact that inefficiencies in the downstream systems have been enhancing inefficiencies in the upstream systems in order to compensate mainly that technical losses. As a matter of fact we have seen that the relationships exist since that reserves capacities levels were the indicator for lower performance and it also has motivated to continue importing electricity.

5.1.11.4 Chile's electricity industry security of supply index

The improvements in security of supply in Chile's electricity industry respond to policy decisions that have carried out the diversification and well distributed energy mix in order to secure the supply of energy commodities that are needed to produce electricity. The industry has been taking advantage of the country's available renewable energy resources to produce electricity based on its hydro power potential. It has minimized the use of fossil fuels in electricity generation. However, the trend in electricity imports dependency is increasing since new power plants have not been developed at the same pulse as the electricity demand's growth. Figure 5.44 shows Chile's electricity industry security of supply performance.

Figure 5.44 Chile’s EISSI

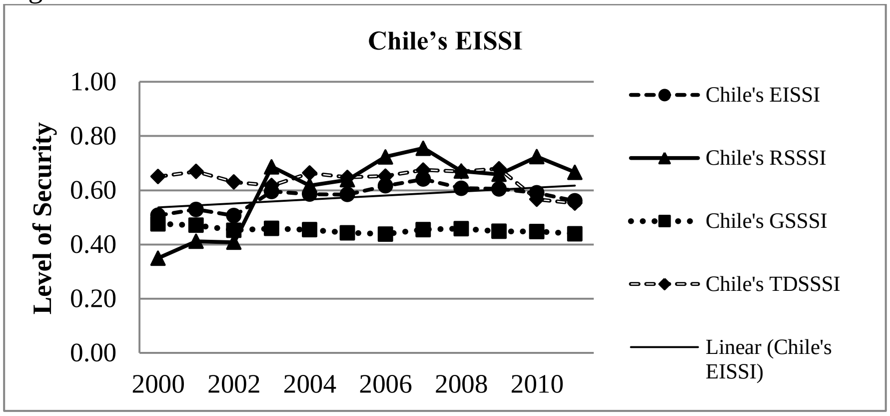


Figure 5.44 illustrates that Chile has a medium level of security of supply in its electricity industry due to the accomplished improvements in the energy resources systems. Also, it has contributed to a quite stable achieved performance in the electricity generation and electricity transmission systems. This country has the highest performance regarding security of supply for its electricity industry in comparison with the other Latin American countries analyzed in this research. The high performance in the energy resource system, securing supplies, has enhanced the output of Chile’s EISSI since it has shown a positive growth over the time. Chile’s EISSI increased, although softly, from 51% in the year 2000 to 56% in 2011.

The implemented policies in diversifying the country’s energy mix reduced risks of shortages due to negative environmental issues as well as electrical infrastructure overexertion. The case of this country in terms of improving energy security of its energy resources system is the most positive example that we have found and it can be a reference to follow by nations lacking enough energy resources domestically to produce electricity and cover demand's requirements. However, the implications of the obtained results from Chile are that the country will continue developing more power plants based on coal or natural gas technologies, but these actions will require the adoption of pollution abatement equipment in order to mitigate high levels of carbon dioxide (CO2) emissions.

5.1.12 Argentina's electricity industry

5.1.12.1 Argentina's energy resources system

Argentina is a net exporter of hydrocarbons, without processing or transformation, which has also impacted negatively in reducing its proven reserves of fossil fuels. The country has not been able to accomplish new discoveries and additions during the period under study. In recent years, this nation started to import hydrocarbons in order to satisfy domestic requirements. This nation has experienced price fluctuations in importing this energy commodity because its prices have been linked to oil prices. In addition, Argentina is highly reliant on regional suppliers which are concentrated in provisions. The risks increased as a consequence of the political instability that has been characterizing the South American region during the past decade. Argentina's main challenge is its energy mix for electricity generation, which is highly concentrated in the use of natural gas. Figure 5.45 shows Argentina's energy resources system security of supply performance.

Figure 5.45Argentina’s RSSSI

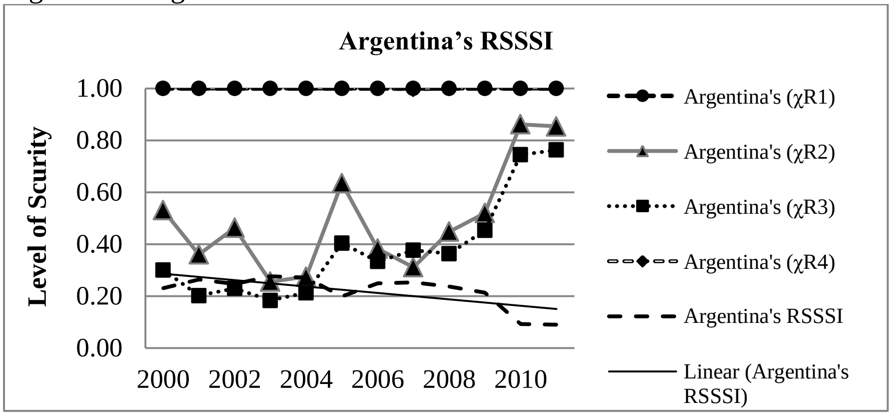


Figure 5.45 shows the performance of the indicators that compose Argentina’s energy resources system security of supply index (RS). The observed behavior of the indicators χR1 and χR2 is that they are over or closer to 1. This situation indicates a low performance of those indicators and risks for the entire system. The nature of χR1 is more dynamic than the other indicators and it obeys that it responds strictly to demand’s requirements, levels of production, and the accomplishment of new discoveries and additions of fossil fuels to the Argentina’s stocks of proven reserves. In the way the proven reserves decreased also energy imports (χR3) raised to compensate the lack of resources to cover domestic demand’s requirements. We can see that χR3 and χR4 have shown the same behavior as the other indicators. It reveals high level of risks and it obeys to the high concentration of employing fossil fuels to produce electricity.

All these facts have affected the performance of the country’s RS index because the level of performance decreased from 48% in the year 2000 to 18% in 2011. We considered that this variation during the period under study has been moderated since the level of security of supply decreased to 14%. It has been as a consequence of the country’s energy mix. The path of Argentina’s RS index is decreasing in a direction closer to 0 that means low level of security of supply in the system. The main reasons have been exporting of domestic resources as well as escalating demand, reducing proven reserves, and creating the country to be a net importer of energy resources to produce electricity.

5.1.12.2 Argentina’s electricity generation system

Argentina’s electricity generation system was almost privatized in order to promote competitiveness through private participation. Only nuclear power facilities and bi-nationals power plants remained in the hand of the State for security reasons and they represent 25% of the total installed capacities. Most of the power facilities were sold during the 90s and currently private corporations own 75% of the total installed capacities. The State is the largest electric utility company in Argentina with a market share of 25.46% as a result that most of its facilities are nuclear and hydro power plants. The electricity generation system has an installed power capacity at the year 2011 of 31.5 GW. At the year 2011 Argentina was 65.7% dependent on thermal power, 26.8% on hydro power, 5.6% on nuclear, and 1.9% on other kind of renewable power.

The development of new power plants growth has registered an average annual growth of 4.62% during the period under study. Domestic production of electricity at the year 2011 reached 113.384 TWh while consumption represented 110.775 TWh, and for the foregoing reasons, the country is performing as a net importer-exporter of electricity, but with positive balance in its favor, because its electricity industry export of 2.609 TWh to neighboring countries. Argentina needs to continue developing new power plants and diversify its energy mix in order to meet demand's requirements. The energy mix and the infrastructure efficiency are the main factors affecting the overall performance of this system. Figure 5.46 presents Argentina's Electricity Generation System Security of Supply Performance.

Figure 5.46 Argentina's GSSSI

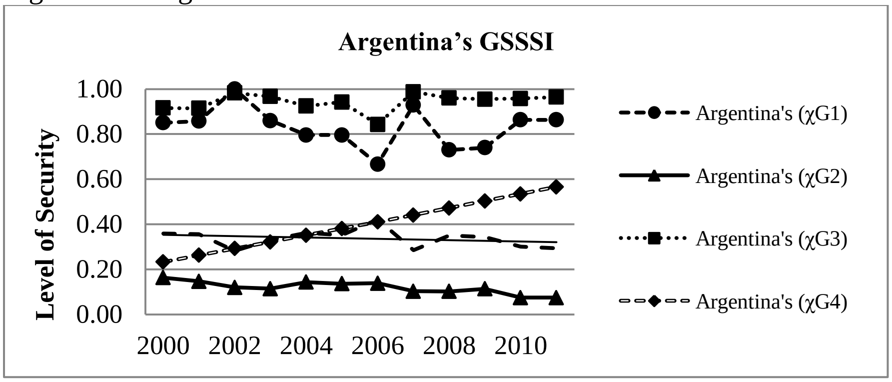


Figure 5.46 shows the performance of the indicators that compose Argentina's electricity generation system security of supply index (GS). The detected behavior of the indicators $\chi G1$, $\chi G3$, and $\chi G4$ is that all of them are increasing towards 1. This situation reflects the increase of risks of reduction in the overall level of security for the GS index. However, it is possible to see that the performance of $\chi G2$ has improved and it has been by means of adding new installed capacities, upgradings or accomplishing maintenances on time in the core equipment of power plants. The main problem of Argentina is its energy mix, which is highly based on

hydrocarbons rather than renewable energy resources. The age of equipment (χG4) is growing progressively and it also affects efficiencies. The implication of this situation is the employment of thermal power plants, which cannot operate at high levels of efficiency in comparison with hydro power plants.

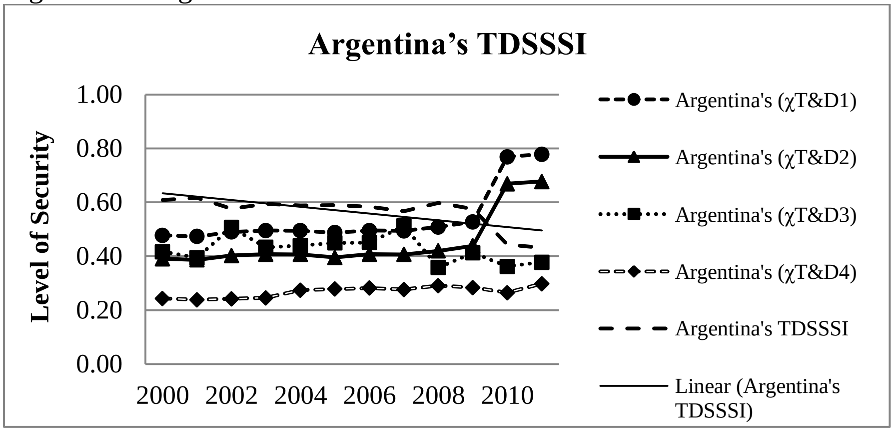
The performance of the Argentina's GS index has decreased from 36% in the year 2000 to 29% in 2011. The system decreased its performance from a medium level to a low high level of security of supply. We considered that this variation, during the period under study, has been measured. If new additions of installed capacities through renewable energy resources are not accomplished in the coming years, the country may not be able to respond by itself to demand's requirements and can also increase its dependency on electricity imports. We believe that reducing the dependency from fossil fuels as well as selecting other type of technologies with high level of efficiencies to produce electricity can stimulate a positive impact on the level of security of the overall system.

5.1.12.3 Argentina's electricity T&D systems

Argentina's electricity transmission and distribution systems are owned and operated by private entities. Electricity transmission is under control of Transporte de Energía Eléctrica en Alta Tensión (TRANSENER), while there are currently 38 distributors of electricity. The distribution companies are spread over several geographical regions. The Management Company of the Wholesale Electricity Market (CAMMESA) operates as a wholesale electricity market. The systems have an installed capacity at the year 2011 of 354,749 kilometers in power lines, while 654,976 MWA in transformer capacities. Infrastructure development has growth at 3.0% in average per annum, while electricity demand has growth at 8.44% in average per annum. The margins between infrastructure development and demand's growth do not allow the systems to count with enough reserves and operate out of technical limits settled on standards.

Total electricity coverage in Argentina is 99.6% (2011). The average number of interruptions annually per customer is around 5, while its duration is around 11 minutes in urban areas. Electricity prices are settled under market mechanisms but they are highly regulated and subsidized. At the year 2011, the prices in average were around US $ 0.022 per kWh, being the lowest ones among the countries analyzed in this study. The main challenges for both systems are the development of a tougher infrastructure that responds to demand's requirements on time as well as works under technical standards to improve efficiency and security of supply. Figure 5.47 shows Argentina's electricity transmission and distribution systems security of supply performance.

Figure 5.47 Argentina's TDSSI



The Figure 5.47 shows that Argentina's electricity transmission and distribution systems security of supply index (T&DS) have decreased considerably over the time. The indicators χT&D1 and χT&D2 have decreased their performance. The track denotes that electricity demand growth has been the main cause for reducing the systems' performance. As we have seen, most of the problems regarding security of supply are as a consequence of electrical infrastructure overexertion, which has carried out heat over itself and increase technical losses (χT&D3) as well as the reduction of the power factor performance (χT&D4).

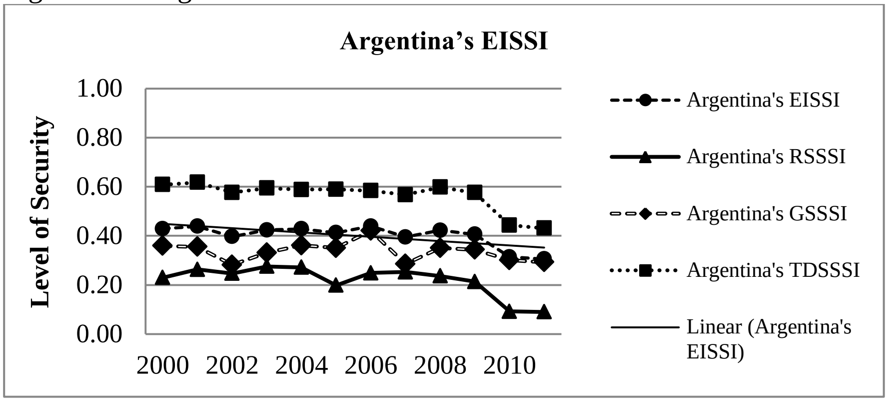
However, the level of losses as well as the power factor in general does not reveal its low performance in the electricity distribution system because it has been compensated with the high performance of the electricity transmission system. The level of losses is dynamic and it has been as consequence that they obey mostly to non-technical factors such as electricity theft.

Security of electricity supply has decreased during the period under study for around 22%, and it has been as a outcome of infrastructure overexertion, production of heat in the electrical infrastructure, and increased level of non-technical losses which behavior has been dynamic. Security of supply has decreased from 43% in 2000 to 31% in 2011. This variation has been normal taking into account that it occurs in twelve years. As a matter of fact, we have seen that the relationships exist since the reserves capacities levels were the indicator of the most dynamic performance of the electricity generation system and it has also motivated to continue importing electricity. These issues have affected security of the electricity generation system negatively.

5.1.12.4 Argentina's electricity industry security of supply index

Argentina's EISSI has shown that the performance of the industry is strictly attached to the resource system outcomes as well as the infrastructure efficiency. The country's electricity industry has a low level of security of supply due to its volatile performance in the energy resources as well as in the electricity transmission and distribution systems. This case is comparable with Honduras regarding its security of supply level. The reduction in the performance of all the systems is the main cause of Argentina's EISSI low output. Argentina has high concentration by employing fossil fuels in its energy mix and it has also based most of its power facilities on thermal power technologies, which cannot reach high levels of efficiency. Infrastructure deterioration due to aging as well as overuse has decreased the electricity industry's performance over the time in terms of security of supply. Figure 5.48 shows Argentina's electricity industry security of supply performance.

Figure 5.48 Argentina’s EISSI



We have seen in Figure 5.48 that Argentina’s EISSI has decreased from 43% in the year 2000 to 31% in 2011. We have seen that security level has decreased in a measured way, since it contracted 12% during the period under study. As a matter of fact, the main causes for diminishing Argentina’s EISSI have been energy resource depletion and exports, as well as electricity demand’s growth. This last factor also has heightened infrastructure overexertion in all the systems. The country’s electricity generation facilities by the nature of the employed technologies in electricity production have a low level of efficiency, which limits the performance of the electricity generation system. Additionally, the industry has not been effective in increasing electrical infrastructure capacities as well as diversifying its energy mix for producing electricity. The developments of new electrical infrastructure have not been at the same rhythm as the demand’s growth.

Argentina’s electricity industry has been affected by a ‘chain effect’ in which the downstream systems, which are closer to the demand

and are vulnerable to its effects, increase the upstream systems in order to compensate their inefficiencies. These implications for this country in order to achieve security of supply in its electricity industry should start by diversifying and selecting less risky energy resources suppliers as well as employing more renewable energy resources in order to minimize risks and through controlled price's fluctuation. The country needs to implement technologies for electricity production that does not only provide more installed capacities and reserves levels, but also operate at higher levels of efficiency.

The electricity transmission and distribution infrastructure need to be vigorous by means of automation and increasing power lines coverage. These actions are required in order to mitigate congestion and overexertion problems, and it can be through build parallel lines, increasing voltage levels or developing distributed generation systems closer to demand. Finally, the national electricity industry needs to operate under well recognized standards in order to keep an optimal level of security of supply.

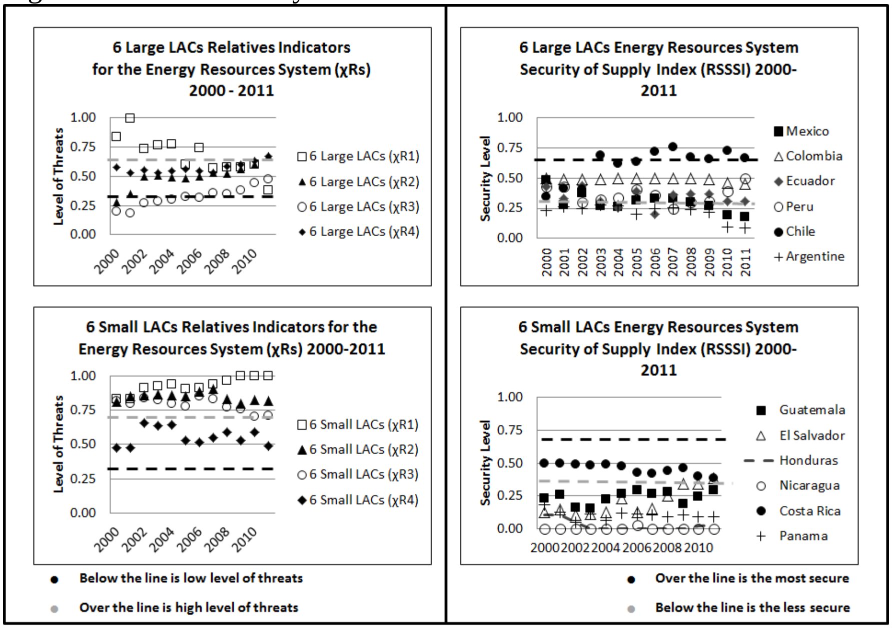
5.2 Results analysis by system & countries' features

In this part of our study we have covered the overall results in term of security of supply per system and per countries' characteristics. We have defined six large Latin American countries such as Mexico, Colombia, Ecuador, Peru, Chile, and Argentina. These nations have more access to energy resources and minerals based on favorable geological conditions as well as large territorial extension. In addition, we have six small Latin American states such as Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama, and belong to the Central American sub-region. We are presenting the achieved performance for each group of countries and system in terms of threats and security levels. These situations allowed us to rank their accomplished performance during the under studied period and also show their behavior.

5.2.1 Energy resources system (RSSSI)

Based on the achieved results, it was identified that South American countries as well as Mexico have a more dynamic and positive performance in their energy resources system security of supply index. It is as a consequence that Central American nations lack large amounts of energy resources. However, it was noticed that both groups are affected for the same kind of threat and they are the causes reducing the overall performance of the energy resource system in terms of security of supply. The figure 5.49 shows security of supply in the energy resources system.

Figure 5.49 RSSSIs analysis 12 Latin American countries



First, it was presented for both groups of nations their accomplished RSSSIs performance. Then, the threats affecting the performance of the system were indicated, which are our relative indicators χRs. As it is noticed, if the relative indicators behave closer to 1 it means high levels of risks and the RSSSI behave in opposite direction denoting a low level of security. These results are presented inside the margins of a low, medium and high security of supply and risks levels. Finally, they were ranked in order to denote their behavior in terms of security of supply in their energy resources system.

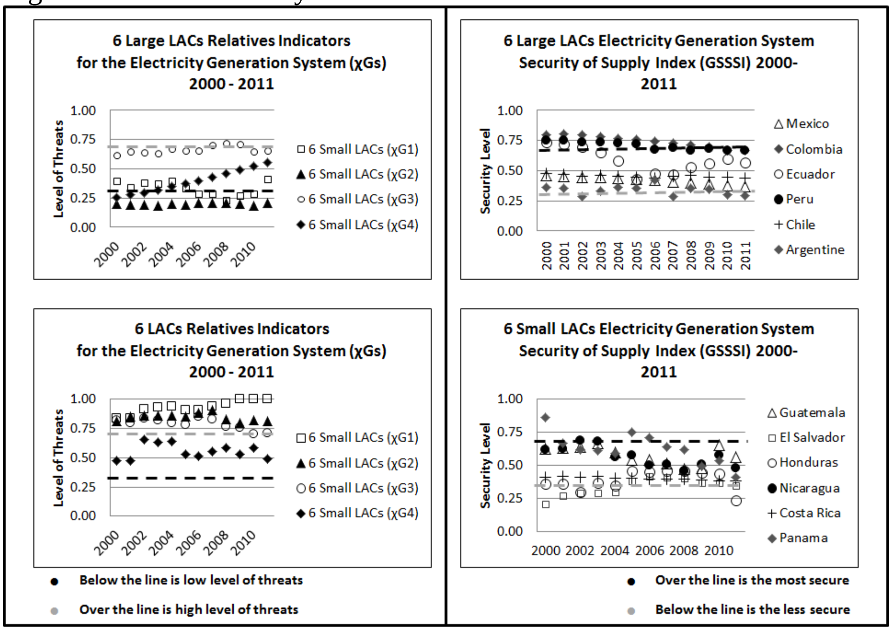
On one hand, the issues decreasing security of supply for the six large Latin American nations are the energy security index price regional energy imports dependency (χR2). This is as result that these nations are increasing their dependency on importing energy commodities to produce electricity ($\chi R3$) and they are concentrating their energy mixes on the use of fossil fuels ($\chi R4$). On the other hand, the small group of six Latin Central American countries has been challenged by their lack of energy resources ($\chi R1$), the energy security index price regional energy imports dependency ($\chi R2$) because they are net importers of energy commodities to produce electricity ($\chi R3$).

Colombia, Peru, Ecuador, and Guatemala are the nations with higher security levels, while the most dramatic experiences in terms of reducing security of supply have been Mexico, Argentina, Honduras, and Nicaragua. Both groups of countries can offer an opportunity to develop energy business in their energy resources system. The cases of Guatemala, El Salvador and Chile have shown a positive behavior since their performances in the energy resource system have improved. These nations have been able to supply demand's requirements through diversifying their energy mix with the use of more renewable energy resources. These nations have decreased their levels of imports of fossil fuels to produce electricity. Furthermore, they have diversified their number of suppliers of energy resources in order to avoid risks of shortage and price fluctuations.

5.2.2 Electricity generation system (GSSSI)

On one hand, it was noticed that among the six large Latin American nations Colombia, Peru and Ecuador are the most secure states in term of electricity supply at the electricity generation system. On the other hand, among the Central American countries Guatemala, Nicaragua and Panama have improved the level of security of supply in their electricity generation system. It has been as a consequence that most of their installed capacities are based on hydropower technologies with exception of Nicaragua, which although its energy mix is highly dependent in thermal power, it has improved efficiencies in its system. The other nations have decreased security levels because of the nature and aging. Furthermore, the less secure nations have generation equipments that are either too old or were based on thermal technologies with low productivity levels. Figure 5.50 shows security of supply in the electricity generation system.

Figure 5.50 GSSSIs analysis 12 Latin American countries



It was observed for both groups of nations their accomplished GSSSIs performance. In general the largest nations have more security levels than the Central American countries. Then, it was shown the threats which are affecting the performance of the system, and they are our relative indicators χGs. As it is noticed, the relative indicators behave closer to 1 it means high levels of risks and the GSSSIs behave in opposite direction denoting a low level of security. These results are presented inside the margins of a low, medium and high security of supply and risks levels. Finally, were ranked in order to denote their behavior in terms of security of supply in their energy resources system.

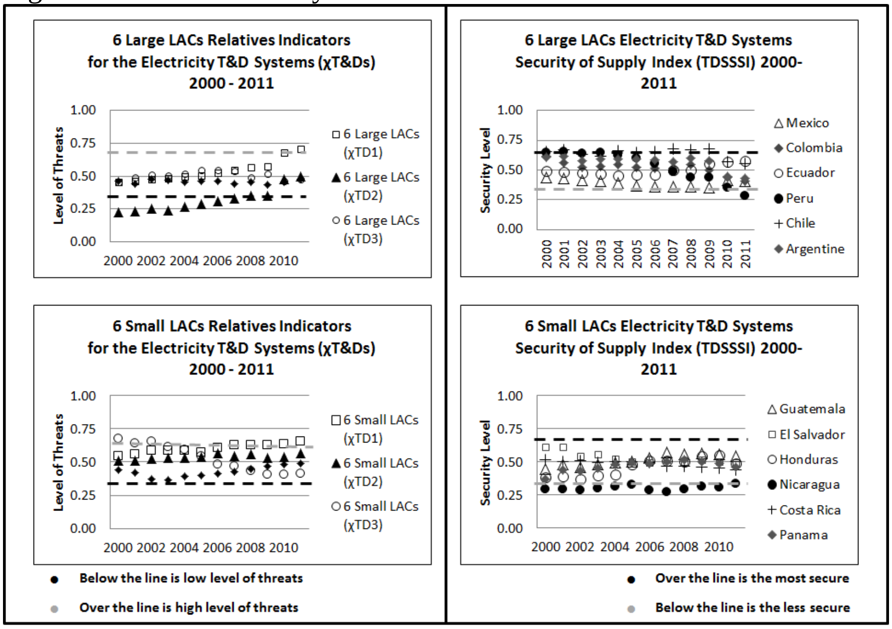
On one hand, the issues decreasing security of supply for the six large Latin American nations are its effective installed capacities (χG1), its reserves capacities factor (χG3) and infrastructure aging factor (χG4). The performance of power plants power plants cannot reach optimal levels of nominal installed capacities and keep free reserves capacities because equipments are becoming old. On the other hand, the small group of six Latin Central American countries has been challenged by their lack of enough installed capacities (χG1). This situation has affected by increasing electricity imports dependency (χG2) since all the nations have worked to accomplish international electrical interconnections, but it has affected positively by increasing reserves capacities (χG3). The upgradings of power plants have stabilized infrastructure aging factor (χG4).

The nations that have based their electricity production facilities on hydropower technologies have shown a more positive behavior in their performances in the electricity generation system in terms of security of supply. It is as a result that hydropower plants operate at higher levels of efficiency and have a long lifespan in comparison with thermal power plants. These two factors contribute positively in increasing not only the installed capacities of the electricity generation system, but also contribute in having availability of reserve capacities. The most secure nations were Chile, Colombia and Peru, while the most dramatic experiences in terms of reducing security of supply have been Mexico, El Salvador, Argentina, and Honduras. However, all the countries offer opportunities to develop power plants because their industries have been deregulated, and the worst scenario might be participating under the figure of independent power producer.

5.2.3 Electricity T&D systems (TDSSSI)

It was identified that the six small Latin American nations have improved in terms of security of electricity supply at the electricity transmission and distribution system, while from the largest ones only Ecuador and Chile. In both cases these eight nations have accomplished bilateral electrical interconnections with neighboring countries. It has contributed in the development of more robust electrical infrastructures. On the other hand, the set of large nations such as Colombia, Peru, Argentina and Mexico have decreased their performance as a result of demand's increasing behavior, while the construction of new infrastructures are not growing at the same rhythm. It is important to do mention that these four countries are after Brazil the most dynamic economies in the Latin American region. Figure 5.51 shows security of supply in the electricity transmission and distribution systems.

Figure 5.51 TDSSSIs analysis 12 Latin American countries



It was noticed for both group of nations their accomplished TDSSSIs performance. In general the Central American countries have more security levels than the largest nations, with exception of Ecuador and Chile. Then, it was shown the threats which are affecting the performance of the system, and they are our relative indicators χT&Ds. As it is noticed, the relative indicators behaves closer to 1 it means high levels of risks and the TDSSSIs behaves in opposite direction denoting a low level of security. These results are presented inside the margins of a low, medium and high security of supply and risks levels. Finally, were ranked in order to denote their behavior in terms of security of supply in their energy resources system.

The issues decreasing security of supply for both group of Latin American nations were of infrastructure overexertion (χT&D 1 and 2), which has impacted in increasing technical and non-technical losses (χT&D 3) and decreased the power factor (χT&D 4). The six large Latin American States were not fulfilling technical standards, the risks of failures in delivering the electricity service increased considerably. The overall performance of the systems was affected because inefficiencies.

On the other hand, the small group of six Latin Central American countries has been improving its security levels in supplying electricity. The improvements have been as a result of the accomplishment of international electrical interconnections among them and the establishment of a common regional electricity market. However, it does not mean that they are exempted of threats which have increased for both utilization factors of transformers (χT&D1) and power lines (χT&D2) as well as the decreased performance of the power factor (χT&D4).

A fundamental factor in improving security of supply for the electricity transmission and distribution systems has been the technological upgradings. The accomplishment of international electrical interconnections has contributed in implementing automation of substations and installation of optical fiber in power lines, which are part of the activities that involves the development of smart grids. These situations contributed in reducing the level of losses and comply with technical standards. In addition, the power factor was improved or stabilized. The achieved results in this research have matched with the theory which sets that, inefficiencies in the electricity industry's downstream systems will increase losses in the upstream systems, and vice versa.

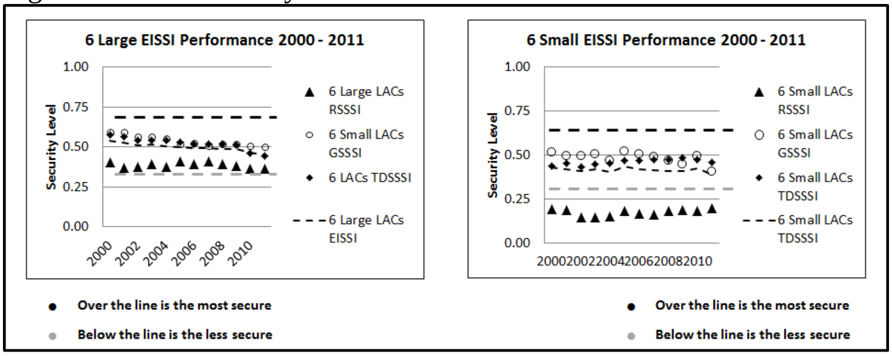
Ecuador, Chile, Guatemala, and El Salvador are the nations with higher security levels, while the most insecure nations have been Mexico, Colombia, Nicaragua, and Peru. In addition, it was noticed that Mexico, El Salvador, Costa Rica, Colombia, Peru, Chile, and Argentina have declined their performances as a consequence of high inefficiencies in the electricity distribution system. It might be possible that countries with lower performance or reducing it might not be able to support regional market integration and the successful accomplishment of power plants in the electricity generation system.

5.2.4 Electricity industry security of supply index (EISSI)

We have found that only four countries have increased or kept positively their performance regarding security of supply of their electricity industries. However, the outcomes for most of the studied countries are ranging inside the limits of a medium level of security of supply. Only Chile, Colombia, Peru, and Ecuador are the group of countries with a higher performance. These nations are ranging inside the limits of a medium level of security of supply. Therefore, Honduras, Argentina, Mexico, Nicaragua, and Panama are the States in which their electricity industries are ranging inside the limits of a low level of security of supply. The causes of a low EISSI performance have been the accomplished performances regarding security of supply in the different systems that compose the electricity industry in the studied nations and which were referred before. In figure 5.52 is presented security of supply in the electricity industry for our 12 studied Latin American countries.

First, both groups of nations their accomplished EISSIs performance is presented. In general both groups of Latin American countries are ranging inside the limits of a medium level of security of supply, with the difference that large nations have better performance in terms of security of supply in their electricity industries. Then, it is shown which systems are affecting the overall performance of the electricity industries. It was identified that for large nations the decrease in security obeys to the outputs of the electricity generation, transmission and distribution systems; while in the case of the Central American nations it obeys to the lack of energy resources and inefficiencies of the electricity generation system. Finally, all the results are presented inside the margins of a low, medium and high security of supply and risks levels. The performance for each nation in its electricity industries was ranked in order to compare with others and denote its behavior in terms of security of supply.

Figure 5.52 EISSIs analysis 12 Latin American countries



The above figure has shown that the tendency for most of the countries has been decreasing security of electricity supply with the exception of Chile, El Salvador, and Guatemala, which have been the States trying to improve security of supply of their electricity industries. The most secure nations are Chile, Colombia, Peru and Ecuador, while the less secure are Nicaragua, Mexico, Honduras and Argentina. Our EISSI has shown that the performance of the electricity industry is strictly attached to the infrastructure efficiency as well as the resource system outcomes. The performance of the large Latin American nations have been decreasing as a consequence of the outputs in their electricity generation and electricity transmission and distribution systems; while the six small States have been affected by their lack of energy resources. These situations have been the main cause in decreasing the EISSI's output.

5.3 Evaluation of our results with previous studies

In this research we have considered a different energy security area, which has not been covered yet. The employed methodology helped us to assess energy security in the electricity industry's supply chain through considering the main risks that can affect infrastructure performance based on available data. The achieved results from our security of supply indexes model concluded that both internal and external factors can influence either positively and negatively security of supply on the electricity industry's supply chain. Table 5.1 shows the evaluation of our results with previous studies.

Table 5.1 Evaluating of our results with previous studies

Author	Results evaluation
Energy resources system The lack of energy resources because of decreasing production levels simply conduces to replace them through imports. Prices became unstable under an imports regime (Cavallo, 2002). Under these situations firms adopt thermal power plant based on fossil fuel commodities (Rose and Joskow, 1990)	Our results are in accordance with their criteria. Countries lacking availability of energy resources have modified their energy mix to produce electricity. Their electricity industries adopted thermal power plants based on oil or gas, and became net importers of fossil fuels. These situations contributed in reducing the performance of the energy resources system in terms of security of supply.
Portfolio diversification reduces risks (Markowitz, 1952).	There are countries which have improved security of supply through spreading their energy mixes. These nations have included a high share of renewable energies and have diversified their suppliers of fossil fuels.
Electricity generation system Effective installed capacities as well as reserves capacities are affected by the specific nature of power plants (type of technology), which influences efficiency and their lifecycle. Also, the accomplishment of maintenances on time. (Seitz, 1971).	We found countries that have based the core technologies of their generation facilities on single cycle steam power plants, which are limited to reach high levels of efficiency in comparison with hydro power plants or combined cycle thermal power plants. The lifespan of power plants is also decreasing and reducing security of supply.
Extreme events in Central America such as hurricanes or heavy rains tend to destroy basic infrastructure. The intensity of hurricanes could increase 10% more during the next decades. This institution has recommended do not build projects in areas subject to flooding and replace the dependence on hydropower for geothermal power plants (UNECLAC, 2013).	We have proposed that policy makers need to consider the development of future power plants based on the adoption of coal or integrated gasification combined cycle technologies equipped with pollution abatement equipment. These actions are in order to stimulate security of supply in the energy resource and electricity generation systems, based on the use of more efficient energy commodities and technologies.
Electrical interconnections with neighbors attempt to improve the lack of capacities and reserves (Ibrahim, 1996).	There are countries facing problems with their generation facilities capacities and their reserves have been running out to accomplish electrical interconnections with their neighbors. These situations have increased electricity imports and dependency, which tend to affect security of supply due to the lack of self-sufficiency.

Continue from Table 4.14

Author	Results evaluation
Electricity transmission and distribution systems Electrical infrastructure requires constant developments, upgradings, and maintenance in order to reduce the probability of failure as a consequence of overloads and exceed voltage limits. Also, accomplish operational activities under the parameters settled by well accepted technical standards (Yeddanapudi 2005).	Electricity demand's growth is faster than the rate in building new electrical infrastructures. This difference is producing infrastructure overexertion and reducing the lifecycle of the infrastructure. Also, these situations are producing heat over equipments and increasing the level of losses and decreasing the performance of the power factor. All of that is reducing the overall performance of the systems in terms of security of supply.

Our results are in accordance with the ones from previous researches, even if there are differences in the approaches employed. Their cases were focused on the qualitative method, while ours was based in the quantitative analysis. Additionally and compared with them, we have extended the criteria about assessing energy security through considering the electricity industry's supply chain, its core indicators, and the influence of principal threats. Finally, the coming Chapter is aimed to present the policy implications that are required to aboard in order to improve security levels in the different systems of the electricity industry.

Chapter 6. Policy Implications

We have defined energy security in the electricity industry as the set of policies, laws, regulations, and standards as well as the actions that must be undertaken to ensure the flow of sufficient amounts of electricity throughout the electricity industry's supply chain until it reaches the final customers without interruption and at affordable prices in accordance with the economic capacity of a nation's inhabitants. Furthermore, we believe that a policy is a decision to guide activities involving a general strategy that accomplished coherent results.[37] Based on these understandings, we believe that policy implications are statements of intention(s), and they have to be implemented through defining activities in a given context. In this research, our scope of study is the electricity industry of twelve selected Latin American countries. Furthermore, it includes the different sectors that make up the industry's supply chain.

In the previous chapter, the achieved results have reflected the situations affecting security levels in the different systems that compose the electricity industry's supply chain in the analyzed countries. In the first two sections of the present chapter, our implications suggest a need to increase security levels in the electricity industry's upstream systems through improving efficiency in electricity conversion. On the other hand, the third section proposes the reduction of intensity of use in the downstream systems. Figure 6.1 presents the relationships between the achieved results and the policies proposed to improve security levels.

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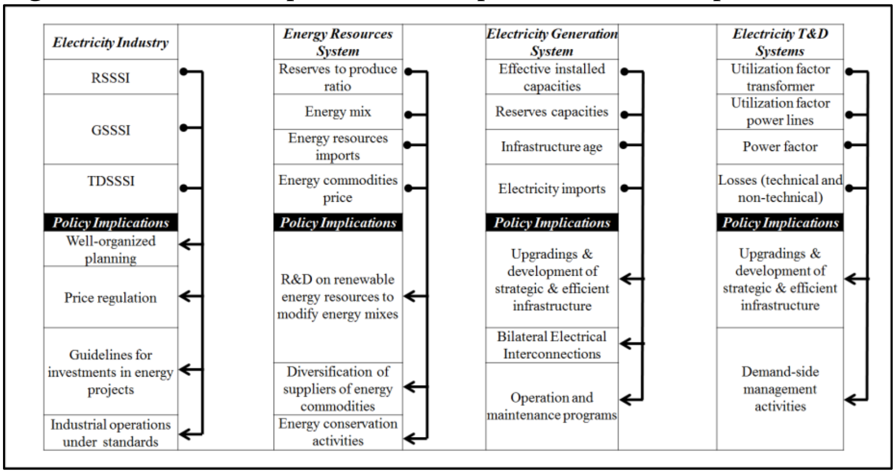
[37] http://www.britannica.com/ governance theories and practice (public policy).

Figure 6.1 Relationships between empirical results and policies



As shown in the figure above, our policy implications have been addressed for each of the systems that compose the electricity industries in the Latin American countries under study. Additionally, we are arguing in favor of the implementation of the proposed policies, which will have effects across the different sectors that compose the society of a given nation. As noted, these suggested policies are large activities that have followed a sequential ordering. It is more than probable that they will require for their accomplishment the formulation of sub-activities in the context of a more specific operational plan. Figure 6.2 illustrates the interactions among policies, systems, and the affected segments of the analyzed states.

Figure 6.2 Policies' interactions

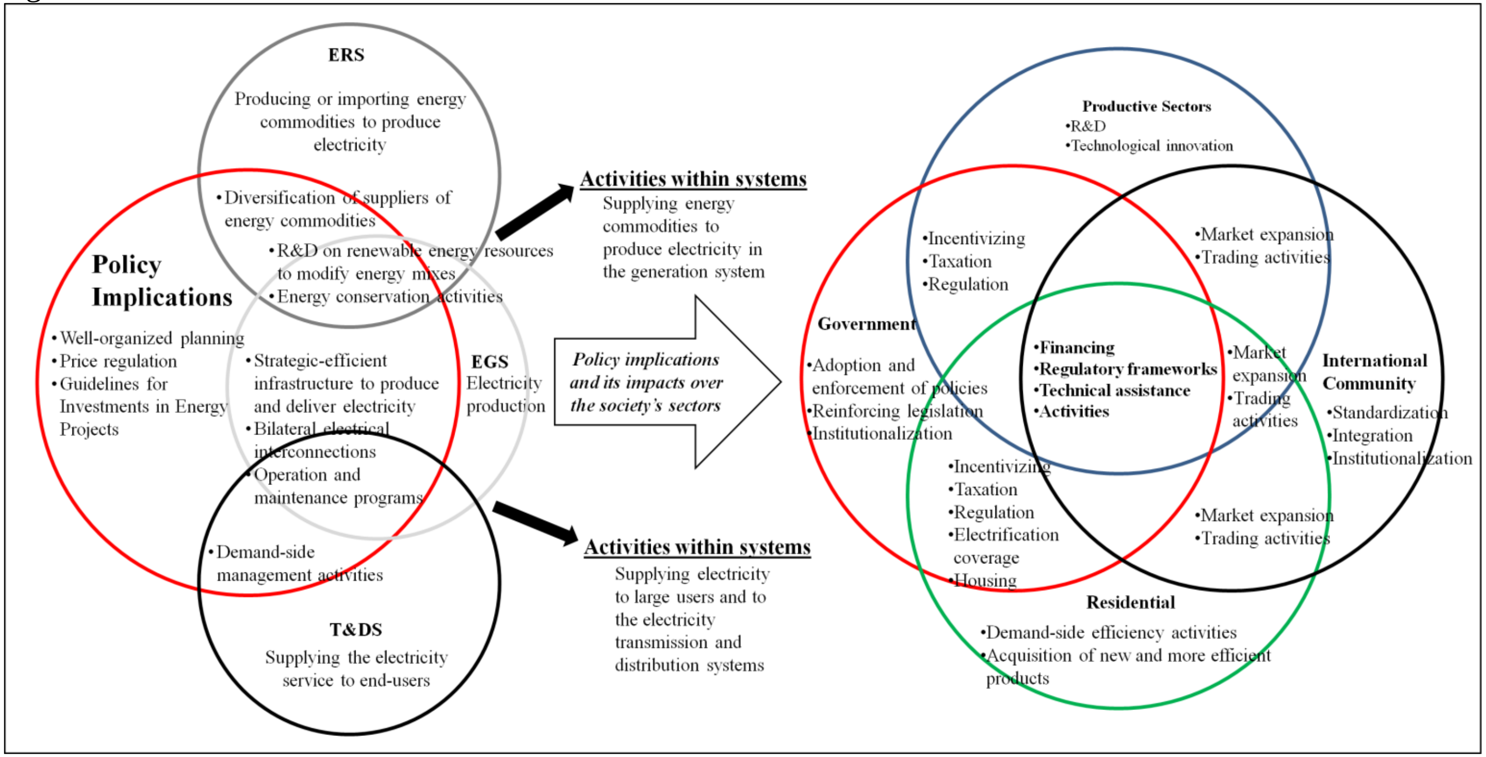


Figure 5.2 provides guidelines for the policies' interactions within systems and regarding the activities that need to be addressed. All of this affects the society because it involves the different sectors that demand electricity as well as the role played by the involved actors. Based on the illustration provided by the figure above, we list our policy implications in the following sections of this chapter.

6.1 Energy Resource System

In this section, we consider policies that attempt to improve security levels in the energy resource system to support continuity of energy commodities that are employed to produce electricity. The suggested policies have been standardized so that they are applicable for all the countries under study. This is based on the common target of improving efficiency in electricity conversion across the systems. The adoption of strategies in the energy resource system is required and will consequently improve security levels. These strategies must aim to remove economic, political, social, and environmental barriers to the development of renewable sources. It is necessary for both large and small Latin American countries under study to encourage investments through governmental support for this system to accomplish the suggested policies and activities.

6.1.1 R&D on renewable energy resources to modify energy mixes

Our strategy is based on the development of renewable energy projects to modify the traditional patterns in electricity generation. It is further based on the development of economic incentives by using as instruments the tax treatment of equipment, materials, and construction costs for renewable energy projects, as well as the fee for electricity transmission activities. Additionally, the use of available information such as investment programs, master plans, project profiles, and prefeasibility and feasibility studies, if possible. This policy applies for all the Latin American nations under study, especially the small set comprising the Central American states. Appendix 2 shows the potential energy resources for each nation to provide an overview of which types of projects can be applied for each state or sub-region. The development of hydro, geothermal, wind, and solar energy projects is greatly expected. It is necessary to provide information about legal matters and labor and environmental issues concerning the construction of such projects.

Among the activities that must be addressed is a detailed review of potential renewable energy projects. Promoting the projects through business rounds and providing preliminary information that is of interest to potential investors. In cases where the information to be provided represents investment costs for the governments, a mutual agreement in which the states will recover their costs from the investors along the project's lifespan might be desired. It is based on the idea that the government's role is not merely to earn profits but also to promote projects associated with the generation of indirect benefits that will greatly affect other areas of the society and the economy.

Concerning the modification of energy mixes, our strategy is based on low carbon development and using as the main instruments existing policies and regulations for the development of hydro, geothermal, wind, and solar energy projects. It will contribute to the modification of energy mixes to produce electricity and to the reduction of excessive dependence on non-renewable fossil fuels for both large and small Latin American countries. Among the activities that must be undertaken is a review of the climate patterns for hydro, wind, and solar energy projects, as well as a review of the geological patterns geothermal energy projects.

The states should account contaminant emissions per sector, detect large polluters, and set reduction targets by building low-carbon scenarios. The projects must apply for certifications in emission reduction units (CERs) and for clean development mechanisms (CDM).[38] In addition, the preparation of feasibility analyses to identify the required investments and targets in terms of the desired renewable energy projects is also required. Then, states should lead the development of an integrated roadmap and the projects' formulations. Finally, they should get support from evaluating existing public policies, barriers, regulations, and financing mechanisms.

It is necessary to support increases in the fees for the electricity transmission system. Activities in this business area should offer an attractive rate of return on investment in the construction of electrical infrastructure. In this case, the fee for the electricity transmission system

[38] http://www.norad.no/en/thematic-areas/climate-change-and-the-environment/mitigation/_attachment/126042?_download=true&_ts=121c95bb9b7

might differ among the countries depending on the nature of the system. For example, in countries such as Guatemala, Colombia, Peru, and Chile, this business area has been deregulated by allowing private participation, so in these nations, the fee in electricity transmission activities should be made more attractive through consideration of an optimal level of profitability for the investors.

On the other hand, in an electricity transmission system that remains a public monopoly, as in the cases of Mexico, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Ecuador, and Argentina, rates of return that allow state-owned enterprises (SOEs) to complete electrical projects are required. The importance of the construction of these associated projects mainly lies in the fact that they reflect the positive impacts of urbanization over increasing the RSSSI's performance. The intention is to develop the projects required to connect production centers to consumption centers.

Finally, for the delivery of incentives, a detailed review of encumbrances by type of expense involved with the development of renewable energy projects and electrical connections from production to consumption centers is compulsory. A proposal must be made for reducing tax rates, which must be transformed into a fiscal stimulus package by enactment of the required legal instruments by the appropriate authority.

6.1.2 Diversification of suppliers of energy commodities

Our strategy is based on increasing the number of suppliers of energy commodities. The main instruments are control reports over imports of energy supplies as well as authorized quotas assigned to each supplier by the authorities in charge of energy matters. This policy applies for all the countries under study because all of them are net importers, but it should be implemented with more urgency by Mexico, Honduras, Nicaragua, Costa Rica, Panama, Colombia, Peru, and Argentina. The selection of suppliers must be based on the criteria of less risk. This can be supported by the country risk classifications of the participants.

It is required that government exercise strict controls over imports of energy commodities to produce electricity as well as impose penalties for infringements. Finally, it is needed to obtain support from evaluating existing public policies, barriers, regulations, and financing mechanisms. It might imply the development of regulations and control mechanisms. The principle is based on avoiding the risk of disruptions in energy supplies as well as reducing price fluctuations due to unstable social, economic, and political issues in the supplier nations.

6.1.3 Energy conservation activities

Our strategy is based on the development of distributed renewable energy centers in residential zones, which involves the production of power on site. A combination of projects based on photovoltaic, fuel cell micro turbines or micro-centralized power plants (with renewable biomasses waste), which are an eco-friendly way of producing electricity must be used as the main instruments. The centers need to be placed in urbanized areas to reduce the consumption of fossil fuels and the associated costs of developing long-distance grids. This is a response in the absence of the required geological conditions for the development of large hydro energy projects, but it can contribute to the modification of energy mixes to produce electricity. This applies to all the nations under study, and Appendix 2 shows the potential of energy resources for each nation to provide an overview of which types of technologies can be applied for each state or sub-region. The development of hybrid schemes is needed to compensate for the intermittency of this kind of energy resources.

All the studied nations are susceptible to the negative effects of El Niño and La Niña, which affect their hydrological cycles. The Central American nations lack oil, and all of them are net importers of its derivative commodities to produce electricity, but they can take advantage of the positive effects of natural phenomena. All these countries have the potential for the development of hydro, geothermal, photovoltaic, and wind energy projects. It is necessary to promote scale economies in the development of the projects, but they must respond to end users' demand growth. Additionally, the completion of storage facilities based on the use of batteries to compensate for the intermittency in the production of energy is compulsory.

The governments need to play the role of a regulator in the construction and energy industries to allow the development of projects. Certifications in emission reduction units (CERs) and for clean development mechanisms (CDM) are needed to encourage investments. In addition, the preparation of feasibility analyses to identify the required investments and targets in terms of desired renewable energy projects is required. Then, they need to lead the development of an integrated roadmap and the projects' formulations. Finally, the governments must get support from evaluating existing public policies, barriers, regulations, and financing mechanisms. The principle is based on the need to support the continuity of energy commodity supplies, the modification of energy mixes, and low carbon emissions.

6.2 Electricity Generation System

In this section, we consider policies that attempt to improve security levels in the electricity generation system to support the continuity of electricity supplies for large users as well as the industry's supply chain. The suggested policies have been standardized so that they can be applicable for all the countries under study. This is based on the common target of improving efficiency in the electricity conversion systems. However, based on the differences among nations, we recognized actions that can respond and apply to the individual characteristics of the states under study. The adoption of strategies in the electricity generation system that improve security levels is compulsory.

These proposals must aim to remove economic, political, social, and environmental barriers to the adoption of more efficient technologies to produce electricity and based on the use of renewable energy resources. It is necessary for both the large and small Latin American countries under study to encourage investment through governmental support for this system to implement the suggested policies and activities. The strategies should aim in increasing efficiencies.

6.2.1 Strategic-efficient infrastructure to produce electricity

Our strategy is based on the construction of power plants through employing more efficient technologies and materials. It involves the construction of hydro and thermal power plants and is intended to replace conventional and less efficient thermal power plants for new ones based on combined-cycle technologies equipped with pollution abatement equipment. These situations might apply to all the nations under study, but particularly to Mexico, Chile, and the Central American nations. These situations can assist in achieving efficiencies and reducing future electricity prices because of economies of scale. The required instruments are fiscal and economic incentives. Fiscal incentives such as tax exemptions are needed for projects based on large investment costs and thus must be extended throughout the projects' life cycle. The economic instruments should include a reduction in taxes on project equipment, materials, and construction costs.

Among the activities that must be undertaken is an increase in the fees for electricity transmission activities. Transmission activities should reflect an attractive rate of return on the investments in the construction of electrical infrastructure. The aim is to attract investors that can develop the projects required to connect power plants with the end consumers. In addition, the governments need to play the role of a guarantor between project developers and financing institutions to reduce risks and costs. State-owned enterprises (SOEs) can participate in the development of power purchase agreements (PPAs) to ensure that the required investments are made.

The diversification of energy mixes will require the construction of facilities for producing power through the use of liquefied natural gas (LNG) or synthetic natural gas (SNG) and pollution abatement equipment, especially in countries such as Mexico, Guatemala, Panama, Colombia, Peru, and Argentina. These are eco-friendly fuels for sustainable development. For imports of energy commodities, it is necessary to undertake trading activities with more than two suppliers. Appendix 2 shows the potential in energy resources for each nation to provide an overview of the types of technologies that can be selected for each state or sub-region.

This is a response to the absence of the required geological conditions for the development of hydro, geothermal, wind, and solar energy projects, but it can contribute to the modification of energy mixes to produce electricity and the reduction of excessive dependence on non-renewable fossil fuels for both large and small Latin American countries. All the studied nations are susceptible to the negative effects of El Niño and La Niña, which affects their hydrological cycles. The Central American nations lack sufficient energy resources, and all of them are net importers of fossil fuels to produce electricity.

The development of long-term contracts between fuel suppliers and intermediary consumers, which transform the commodities into electricity, is needed. It has to respond to end users' demand growth requirements. In addition, the establishment of storage facilities, for which the states must provide economic incentives to reduce investment costs, is compulsory. The governments need to play the role of a guarantor between project developers and financing institutions to reduce risks and costs.

State-owned enterprises (SOEs) can participate in the development of power purchase agreements (PPAs) to ensure that the required investments are made.

The potential projects need to apply for certifications in emission reduction units (CERs) and for clean development mechanisms (CDM).[39] In addition, the preparation of feasibility analyses to identify the required investments and targets in terms of the desired energy projects is required. Then, they have to lead the development of an integrated roadmap and the projects' formulations. Finally, the governments must get support from evaluating existing public policies, barriers, regulations, and financing mechanisms.

6.2.2 Bilateral electrical interconnections

Although bilateral electrical interconnections among the countries under study have been established, there is still potential for the development of more connections along their border areas with neighboring States. These situations can improve the security of the electricity supply among the states. This applies to all the under studied nations. Appendix two shows the potential energy resources for each nation to provide an overview of the types of technologies that can be applied to each state or sub-region. The development of hybrid schemes is needed to compensate for the intermittency of these kinds of energy resources.

[39] http://cdm.unfccc.int/filestorage/V/K/1/VK1I5G0CSRZYB8JCSMF1420747JTS7/

Our strategy encourages the development of interconnections to promote electricity exports and strengthen regional market integration. Economic incentives, which can include the tax treatment of equipment, materials, and construction costs for renewable energy projects, as well as for the accomplishment of electricity transmission activities, are needed for the development of large renewable energy projects, thermal power projects based on the use of LNG or SNG, and the construction of electrical grids and substations. In addition, the harmonization of policies, regulations, codes, and standards is compulsory to develop the regional electricity markets.

The nations under study need to support their bilateral electrical interconnections with the development of a long-distance and independent transmission line based on high-voltage direct current (HVDC) technologies, which allow interconnectivity not only among states but also among both the Mesoamerican and the Andean sub-regions. This will involve the development of large projects and the unification of technical standards and operational protocols. It will take advantage of renewable energy resources that are located distantly and avoid the intermittency of these types of resources, and HVDC systems might be less expensive and suffer fewer electrical losses.

The projects can be synchronized in a common grid for both Latin American sub-regions and the North American electricity market, which will promote electricity production using shale gas. All of them may follow the example of the European super grid, which is the largest synchronous electrical grid in the world. In both sub-regions, through developing a super grid and using automation and telecommunications systems, it might be possible in the future to unify the super grid and smart grid capabilities into a completely efficient network in both sub-regions.

However, these electricity transmission activities should offer an attractive rate of return on investment in the construction of electrical infrastructure. Regional market operators as well as regulators must be institutionalized to manage and control trading activities among the states. These are the functions that governments need to enforce and support by any means. The intention is to attract investors to develop the projects required to connect production centers to consumption centers. Electricity exports need to be controlled in terms of the resources or fuels that are to be employed for their accomplishment. The exports must be organized in a hierarchical way, such that the production of electricity with the most efficient fuels is retained for domestic consumption.

6.2.3 Operation and maintenance programs

Our strategy is based on determining the optimal preventive maintenance frequency. The main instruments are centralized control reports and maintenance programs by market operators and regulators regarding the performance of equipment in power plants, substations, and power lines. In addition, they include economic incentives for importing equipment as well as the costs associated with the maintenance activities. This is a response to the escalation of the availability, reliability, and efficiency of electro-mechanical equipment in power plants, substations and power lines. These situations are applicable for both large and small groups of Latin American countries. All the studied nations are susceptible in their electricity generation, transmission, and distribution systems to the negative effects of the use of equipment as well as the aging factor of these.

Among the activities that must be performed is the development of a centralized control system regarding the performance of power plans, substations, and power lines, as well as a centralized schedule for programming and performing maintenance activities. These instruments must be interrelated with the participants in the electricity generation system, electricity transmission and distribution systems, market operators, and regulatory institutions. Maintenance programs must respond to equipment performance, life cycle, and demand requirements. The attainment of corrective maintenance programs must be based on the reduction of the expected average performance of electromechanical equipment due to its usage and age. The failure to complete operation and maintenance programs on time will require the imposition of economic penalties on electricity producers for failing to carry out their duties and for risking the functioning of the entire system.

6.3 Electricity Transmission and Distribution Systems

In this section, we consider policies that attempt to improve security levels in the electricity transmission and distribution systems to support the continuity of electricity supplies along with the industry's supply chain until it reaches the end consumers. The suggested policies have been standardized so that they can be applicable in all the countries under study. This is based on the common target of improving efficiency in the electricity conversion systems. This applies to all the under studied nations.

The adoption of strategies in the electricity systems that contribute in improving security levels is required. These must aim to remove economic, political, social, and environmental barriers to the adoption of more efficient technologies in delivering the service. It is necessary for both large and small Latin American countries under study encourage investment through government support for these systems to accomplish the suggested policies and activities. The strategies should be aimed to increase efficiencies, including from the demand.

6.3.1 Strategic-efficient infrastructure to deliver electricity

Our strategy is based on the development of a statutory framework that should ensure the security of electricity supplies along the industry's supply chain until it reaches the end consumers. It is intended to reduce intensities and avoid inefficiencies in electricity consumption. The required instruments are mainly economic incentives. Based on these accomplishments, it might be possible to achieve efficiency through the development of more robust electrical infrastructures. Among the activities that must be undertaken is a detailed review of encumbrances by the type of involved expense in the completion of audits and related projects with the improvement of efficiency levels in electricity transmission and distribution activities, as well as in end users' consumption habits. A proposal for reducing tax rates must be made, which must be transformed into a fiscal stimulus package by the appropriate authority enacting the required legal instruments.

It is necessary to identify areas with high levels of technical and non-technical losses, where the development of smart grid activities must be focalized. The development and adoption of harmonized technical regulations and standards is compulsory. In addition, is required an increase in the tariff on electricity transmission and distribution activities to accomplish investments in new infrastructures as well as upgrades. These developments must be established on technical as well as socio-economical bases. Controls and transparency mechanisms in the execution of the investments by the electricity transmission and distribution companies, whether they are state-owned enterprises (SOEs) or private entities, must be established as well.

Activities related to the development of smart grids require the establishment of substations and power lines under the standards set by the International Electrotechnical Commission (IEC). Furthermore, installing advanced infrastructure for the modeling, metering, analysis of operations and consumption levels, the completion of telecommunications activities to support interoperability mechanisms and manage operations via remote control. Appendix 3 shows the activities that must be implemented by each country to improve supply security in the electricity transmission and distributions systems as well as to support smart grid implementation. Governments need to take responsibility for supporting the development of energy-efficiency projects with the support of financing institutions. In this geographical zone, the financing mechanisms include those of the Inter-American Development Bank (IADB) and the Central American Bank for

Economic Integration (BCIE). The former institution can support the development of projects across the continent, while the latter can serve the Central American nations.

Governments must regulate the development of future residential projects. This involves the establishment of codes based on standards that seek to improve efficiency in electricity consumption. Future residential complexes must include enhancements to their structural design as well as their electrical systems. The government should establish mechanisms for subsidizing the construction of new residential centers. The codes must be established under the technical standards set by the International Electrotechnical Commission (IEC). Among the main contents are issues associated with insulation, smart metering, air conditioning, fuses, power plugs and sockets, circuit breakers, switches, cables, lighting, household appliances, electrical installations, protection systems against electric shocks, and electromagnetic compatibility.

Public R&D investments in rural electrification projects are still needed because the low consumption levels in these areas will not make private investment feasible. Governments must continue to support these missionary activities while providing training for the population about how to use electricity efficiently. The promotion of productive uses of electricity can reduce poverty levels in rural zones through developing commercial activities as well as micro-industries. Rural electrification through photovoltaic systems will require strong governmental support for reducing investment costs, and these kinds of projects are recommended for areas that are geographically isolated from the traditional grids.

6.3.2 Demand-side management activities

Our strategy is based on developing efficient uses of electricity in the main sectors that compose the societies in all the Latin American countries under study. The instruments required for its accomplishment are regulation, institutionalization, advertising, and economic resources. Based on these developments, it might be possible to achieve an optimal electricity distribution system that serves efficient consumer markets. By consuming less electricity, efficiencies along the electricity industry's supply chain will be obtained, which will positively affect the productivity of the industry's upstream systems. In addition, end consumers might save economic resources and achieve greater returns from their installations.

We have divided the activities need to be implemented into three parts. First, we considered the activities that need to be addressed by the governments. It is desirable to establish institutions in charge of implementing energy-efficiency activities in the various sectors of the society. The states are required to transfer funding to promote the completion of the activities and to provide incentives to the demand side to encourage the adoption of a new culture oriented toward efficiency. In addition, governments need to establish mechanisms for subsidizing the costs of accessing more efficient products. There is a need to implement codes that regulate the production or import of efficient goods. The required codes for demand-side management activities also need to be addressed under the technical standards set by the International Electrotechnical Commission (IEC).

The main items that need to be regulated when they are acquired by customers are air conditioning equipment, fuses, power plugs and sockets, circuit breakers, switches, cables, lighting, household appliances, electrical installations, protection systems against electric shocks, and electromagnetic compatibility. At the municipal level, it is necessary to provide efficient street lighting and traffic lights. Undertake trainings in regarding productive uses of the electricity to encourage the development of micro-industrial and commercial activities in rural areas, promote the use of appliances with energy-efficiency labeling, and the implementation of schedules for rational uses of electricity.

The activities that must be undertaken by end customers in the residential sector include the replacement of incandescent lamps and the efficient uses of refrigeration, air conditioning, and appliances. Finally, in the commercial and industrial sectors, it is necessary to optimize the electromotive force, the use of boilers, the implementation of efficient lighting systems, the optimization of the cold chain, and participation in co-generation or self-generation. Furthermore, the establishment of a comprehensive electricity management system with an emphasis on the business outputs is required.

Electricity consumption is a key parameter in the development of the Latin American region. For the aforementioned reasons, proper management is a necessity to increase productivity through the implementation of corrective actions in electrical installations. Awareness, rational use of electricity and the implementation of energy saving measures are essential to achieve the optimization of energy resources and reduce the utilization factors in electrical equipment such as the power lines and substations.

6.4 The Electricity Industry

6.4.1 Well-organized Planning

Our strategy is based on reducing the risks that emerged after deregulation processes were enforced in the Latin American countries under study. There is uncertainty and complexity in the planning processes of the electricity industry. The siting, timing, and capacities of new generators are becoming permanently uncertain. Furthermore, there is considerable uncertainty regarding capacity requirements and lengthened lead times for the construction of electricity transmission and distribution projects. The planning must include several scenario analyses for resource production and the development of power plants and electrical infrastructures to deliver electricity service, the identification of projects and screening, the selection of candidate projects, forecasting of demand growth, determination of the optimal project capacity, uncertainty and risk assessment, and economic assessment or investment analysis.

Assessing security levels is required for both the upstream and downstream industry systems. The required instruments are control reports in a sub-regional or regional context. These tools can contribute to the expansion of energy resources, power plants, and regional grid projects. A basic master plan that includes all the systems should be prepared on a national, sub-regional, or regional scale for effective economic and industrial development and a reliable power supply because it is better than multiple small projects, as it is happening after deregulation processes were enforced. The implementation of software and modeling is necessary to achieve accurate planning along the industry's supply chain. These activities shall be carried out under the responsibility of either the market operator or the industry's regulatory agency. The intention is to prevent future risks among the systems that might arise from improvement in one of them without improving the others.

The nations under study can provide detailed information about their plans or programs for the consecution of regional market integration as well as support economic growth and business opportunities. In addition, all these issues can be useful in implementing more accurate policies and actions in the future, which can improve quality in supplying electricity service for end customers along the industry's supply chain. Among the required activities is the involvement of all the participants in the different systems that compose the electricity industry, governmental offices associated with energy and electricity issues, and private-sector associations (industrial and trade chambers). Furthermore, the participation of regional international organizations and international cooperation agencies might be necessary to achieve technological progress and financial support.

6.4.2 Price regulation

Our strategy is based on providing the necessary enticements to ensure investments in electricity transmission and distribution systems.

The main instrument is the price of supplying electricity service. It is necessary to complete studies that can set rates of return on investment on in the expansion of electrical infrastructure. These rates do not have to be kept in the hands of private participants or state-owned enterprises (SOEs). The resources need to be designated to develop well planned projects that can increase security levels in these systems. These rates need to be charged for electricity service to end-customers, and they differ from those that are aimed to compensate for capital investments for profitability purposes. It is required for regulatory agencies and other governmental dependencies involved in the protection of end consumers to establish control mechanisms to ensure the disbursement of the resources in the programmed projects as well as transparency in the execution of the investments.

Governments must target the delivery of subsidies for electricity service based on socio-economic considerations. It is necessary to take into account poverty issues, income levels, and electricity consumption ranges. Subsidy schemes for electricity consumption should also be established based on demographic factors such as low-income areas. The economic considerations should address economic activities and household income (retirees, welfare, single mothers, and unemployment). Other socio-economic factors can include requisitions from the distributor or consumption levels.

6.4.3 Guidelines for investments in energy projects

Our strategy aims to provide direction for future investments in energy projects in the different systems that compose the electricity industry. Our targets are to improve the efficiency of foreign direct investments and to take advantage of the positive aspects provided by natural phenomena. Governments must require the development of renewable energy projects based on hydro and solar power and take advantage of the positive aspects provided by natural phenomena. Al the under studied Latin American countries have potential for the development of these kinds of projects. The states need to provide available information such as investment programs, master plans, project profiles, and prefeasibility and feasibility studies, if possible.

Ministries associated with energy issues as well as regulatory agencies must regulate, control, and authorize the development of future projects through foreign direct investments. The regulations must encourage the development of greenfield projects in the different systems because they provide more benefits than single merger and acquisition (M&A) activities. The development of fossil fuels, especially in Guatemala, Colombia, Peru, and Argentina, must be linked to with domestic processing and keeping some margins over production levels to satisfy domestic demand for electricity. Additionally, for all the nations, M&A in the electricity transmission and distribution systems must be allowed in cases where the expansion of physical infrastructures and the achievement of technological upgrades can be ensured. These actions need to be taken as part of domestic policies regarding international cooperation. Among the activities that must be undertaken is a detailed review of existing legislations, and if the policies are not included, a proposal for their efficient implementation must be developed.

6.4.4 Industrial operations under the performance of standards

Our strategy is based on achieving optimal operational levels by adopting and following well accepted international standards that are applicable for each of the systems that compose the electricity industry. The main instruments are economic incentives and controls. It is important for all the under studied nations to guarantee quality in supplying electricity service for the different sectors of their societies. By these means, the electricity industries of the under study nations will be able to make better use of energy resources. Furthermore, they might improve the flows of electricity along the systems, and improve controls, interchangeability, and compatibility across systems and with neighbor countries, pursue safety, health, environmental protection, trade facilitation, and engage in technological transfers.

The nations under study must establish a common regional standardization body to develop harmonized standards for the region. The regional and national regulatory bodies also need to adopt well recognized international standards that are applicable to the operations of each of the systems in their electricity industries. The states need to provide incentives to encourage the companies involved in each of the systems of the electricity industry's supply chain to obtain certifications from international and regional standardization agencies to ensure that their operational activities are being completed under the performance of standards applicable to these systems. The expenses of certification must be deductible from tax obligations. The regulatory bodies must establish accurate controls and sanctions for the infringement of those principles.

Chapter 7. Thesis Conclusions

7.1 Energy Resource System (RSSSI)

From our index analysis results, it was found that supply security in the energy resource system depends on access to energy resources to produce electricity. For the large countries as well as Guatemala, this factor has been affected when the nations under study did not add new proven reserves, reduced stocks, and were deficient in the development of renewable energy resources due to lack of facilities for transformation or a lack of access to the regions where energy sources are located. These situations have occurred in most of the studied countries. However, Chile, Colombia, and Peru are the countries with higher security levels. In addition, it is expected that nations can improve security levels by adopting more renewable energy and implementing energy conservation measures.

Most of the studied Central American nations have faced problems regarding the availability of energy resources to produce electricity. These nations lack sufficient energy resources to produce electricity due to geological conditions, as in the cases of El Salvador, Honduras, Nicaragua, Costa Rica, and Panama. In addition, there has been a decline in proven reserves and deficiency in the development of renewable energy resources because of a lack of facilities for transformation or inaccessibility of the regions where the resources are located, as in the cases of Mexico, Guatemala, Colombia, Ecuador, Peru, Chile, and Argentina. These conditions drove these countries to adopt thermal power plants over the past two decades, based on single-cycle steam power, which increased crude oil imports. At the same time, the prices of these commodities were low compared with those offered in the international markets over the last five years.

Countries such as Costa Rica, Colombia, Ecuador, and Peru have a high share of hydro power in their energy mix to produce electricity; however, these nations have suffered negative environmental effects in producing water for hydroelectricity due to the natural phenomena of El Niño and La Niña. Under these conditions, their electricity industries adopted thermal power plants and the use of fossil fuels from other countries in the region to mitigate the negative effects. The results have shown that these nations have faced the "chain effect" among systems in their electricity industries. This has been the case for Mexico, Honduras, Nicaragua, Panama, Ecuador, and Argentina. The most dramatic experiences in terms of reducing supply security have occurred in Mexico, Nicaragua, and Argentina.

Mexico and Argentina have been reducing their proven reserves to increase production levels since demand is increasing. These nations have faced problems in finding new discoveries to add new proven reserves. In the case of Mexico, it has started to shift its technology to produce electricity from oil to natural gas. Mexico's gas imports, which come mostly from the United States, have grown from U.S. $2.9 thousand million in 2000 to U.S. $23.9 thousand million in 2011.[40] Argentina has also increased its energy imports due to the reduction of its own resources

[40] Latin American Association of Integration, International Trade Information System (Asociación Latinoamericana de Integración [ALADI-SICOEX] 2012). Available at http://www.aladi.org/

and as a consequence of the government's decision to nationalize the main companies related to energy exploration and production in 2012 to neutralize further risks to energy supplies.

The cases of Guatemala, El Salvador, and Chile have shown positive performance in the energy resource system in terms of supply security. These nations have been able to meet demand by diversifying their energy mixes with the use of more renewable energy resources. These nations have decreased their levels of fossil fuel imports to produce electricity. Furthermore, through diversification of their energy resource suppliers, the risks of shortage and price fluctuations have been reduced. In importing energy resources, even under oligopolistic conditions, at least three suppliers are required to minimize the risk of supply interruptions because, if one of the suppliers fails, its quota can be distributed proportionally between the other two providers. These policy decisions were adopted by these countries to minimize the negative effects of a lack of energy resources as well as external factors.

7.2 Electricity Generation System (GSSSI)

In our study, we have found that supply security in the electricity generation system depends on having sufficient installed capacities to produce electricity. Chile, Colombia, and Peru are the countries with higher security levels. The equipment of generation facilities is subject to the restrictions established by their nominal capacities. In addition, both effective capacities and the availability of reserves can be diminished because of negative environmental issues that are affecting the production of water or biomass employed as raw materials to produce electricity.

Losses in the electricity industry's downstream systems (distribution and transmission) pull over inefficiencies in the upstream systems (generation and resources). In this case, the losses are compensated for by demanding the establishment of more power generation capacities as well as energy sources for electricity production, and reserves tend to decrease because of this wastefulness. To improve security levels, the adoption of efficient technologies based on the development of renewable energy projects (hydro, solar, and geothermal) is necessary. Moreover, the effectiveness in the realization of operation and maintenance programs in power plants is mandatory. Finally, it is required to build electrical interconnections, promote exports, and strengthen regional market integration.

All the analyzed nations are suffering from infrastructure deterioration because the age of the power plants is increasing steadily and as a consequence of the fact that these nations have thermal power plants with a life cycle of a maximum of 25 to 30 years. Our study covers 12 years, and it shows that the equipment lifespan has decreased by 40% to 50%. Moreover, infrastructure deterioration has caused the reduction of nominal installed capacities as well as the availability of reserves as a consequence of a lack of timely maintenance and the peculiar nature of the power plants, which cannot reach high levels of efficiency.

All these issues have enhanced electricity imports to compensate for inefficiencies and meet demand. These nations do not have enough power generation facilities to supply electricity, so they have developed international electrical connections to solve their problems. The most dramatic experiences in terms of reducing supply security in this system have been Mexico, El Salvador, Honduras, and Argentina. Our results match the theory about production frontier limits for installed capacities. In addition, with inefficiencies in the electricity industry's downstream systems, losses in the upstream systems were increasing and vice versa.

The case of El Salvador is an exception because the country has been installing new generation capacities with high efficiency levels, which have also reduced electricity imports. The country has established an international electrical connection that allows the importing of electricity from the Central American electricity market to meet demand. The country has significantly improved its electricity transmission system infrastructure and minimized inefficiencies that have influenced the performance of the electricity generation system. These situations are noteworthy because this nation is the smallest in territorial range compared to the other analyzed countries. This situation has provided an advantage for El Salvador to improve the electrical infrastructure in one of its electricity industry's downstream systems, and it has greatly improved performance in terms of supply security in the upstream systems.

7.3 Electricity T&D Systems (TDSSSI)

Supply security in electricity transmission and distribution systems requires a robust infrastructure that responds to demand. In addition, there is a very important issue that affects the level of supply security for both systems, which is meeting technical standards that reduce the risk of failures and shortages in supplying electricity to end customers. Ecuador, Chile, Guatemala, and El Salvador are the nations with higher security levels at the electricity transmission and distribution systems. The Central American countries have improved their electricity transmission infrastructure by creating a regional electricity market. This situation was created by either net exporters or net importers of electricity. On one hand, it has reduced inefficiencies in the system. However, in the cases of El Salvador and Costa Rica, the low performance was a consequence of high inefficiencies in the electricity distribution system, which has reduced the overall performance of the T&DS index in terms of supply security. Moreover, the low performance of these countries might affect the operations of the Central American regional electricity markets negatively and discourage investments in neighboring nations.

Mexico has experienced interconnection with the U.S., Colombia and Ecuador with Venezuela in the northern region, and Chile with Argentina in the southern region of South America. These nations have improved their electricity transmission systems because they found a fast solution to meet demand as a consequence of economic growth, especially in Colombia and Peru. Their rate of building electrical interconnections is higher than their rate of developing new energy projects that also compensate for the electricity demand growth rate. The low performance of Mexico, Colombia, Peru, Chile, and Argentina is a consequence of high inefficiencies in the electricity distribution system and because the level of losses is higher due to their extensive territorial extension. These situations have also reduced the overall performance of the T&DS index in terms of supply security. In general, the most dramatic experiences in terms of reducing supply security in this system have occurred in Mexico, Colombia, Nicaragua, and Peru.

Large Latin American countries such as Colombia, Peru, Mexico, and Argentina have experienced decreased performance in terms of the supply security in their electricity transmission and distribution systems. The most dramatic cases we have found are Peru, Colombia and Argentina, whose levels of security dropped 36%, 21%, 18%, respectively, over a period of twelve years. These changes were large and fast, and not only reflect infrastructure overexertion but also respond to a high level of non-technical losses in the electricity distribution system. Furthermore, the level of losses has negatively affected the power factor performance. These nations were not meeting technical standards, so the risk of failures in delivering electricity increased considerably. The overall performance of the electricity industry, which is linked to efficiencies or inefficiencies in these systems, was also affected.

A fundamental factor in improving supply security for the electricity transmission and distribution systems in the Central American nations has been technological upgrades. The establishment of international electrical interconnections has contributed to the automation of substations and the installation of optical fiber in power lines, activities associated with the development of smart grids. These situations reduced the level of losses and complied with technical standards. In addition, the undertaken measures have improved or stabilized the power factor. Even though the overall performance of the systems has dropped in these countries because of negative issues in the electricity distribution system, upgrades have minimized the negative effects, and the reduction in the overall performance ranged from around 7% to 14% at a maximum. The results obtained in this study match the theory that posits that inefficiencies in the electricity industry’s downstream systems will increase losses in the upstream systems and vice versa.

We have determined that the energy resources system of the countries under study can support the development of new power plants. Moreover, the interconnectivity offered by the two sub-regions allows trading activities among nations. However, it is important to know the risks that can affect investment decisions. For example, it might not be feasible to build a power plant in Colombia or Guatemala with the purpose of supplying electricity to their respective regional markets. This presumption is based on the fact that the function of the liaison nations is not secured. There is no information about the capacities of the intermediary states, which link the generator and consumer countries.

Based on the study results, we have seen that the electricity industries of Mexico, El Salvador, Costa Rica, Colombia, Peru, Chile, and Argentina have shown low performance in terms of supply security in their electricity transmission and distribution systems. It will be risky to invest in electricity generation projects in these countries if the problems persist because it is not secure enough to establish trading activities in the regional markets. In this study, information about the capacities of the intermediary states was collected and provided. Our study can be used in making investment decisions concerning the development of power plants in any of the countries in each sub-region. Furthermore, it provides criteria about which nations should be avoided until their neighbors improve the security levels in their electricity transmission and distribution systems.

The improvement of supply security in the associated systems can significantly ensure the degree of security in the electricity transmission and distribution systems. The positive behavior of the energy resource systems encourages the development of distributed generation systems based on renewables, such as photovoltaic or micro-hydro power projects. However, for all the under studied nation it was determined that electricity generation systems tend to behave negatively in the absence of a well-organized planning system that allows the equal development of the systems. Otherwise, improvements only in the electricity generation system might cause problems of traffic congestion in power lines and the overexertion of physical capacities in the downstream systems.

7.4 Electricity Industry (EISSI)

In our analysis, we found that only three countries have increased or maintained their performance regarding the supply security of their electricity industries: Chile, Guatemala, and El Salvador. However, the outcomes for most of the studied countries exhibit a medium level of supply security. Only Chile, Colombia, Peru, and Ecuador are in the group of countries with higher performance. These nations exhibit a medium level of supply security. Therefore, Honduras, Argentina, Mexico, Nicaragua, and Panama are the states whose electricity industries exhibit a low level of supply security. The causes of low EISSI performance are the poor performance of the different systems that compose the electricity industry in the studied nations.

Decreasing security of the electricity supply has been a trend for most of the countries, with the exception of Chile, El Salvador, and Guatemala, which have been the only states to improve security. Our EISSI has shown that the performance of the electricity industry is strictly linked to infrastructure efficiency as well as to the resource system outcomes. These situations are the main factors affecting the performance of the electricity industries in the analyzed countries. In addition, investments in infrastructure additions and timely maintenance are required to maintain or increase the security and continuity of the electricity supply. To improve security levels, the development of renewable energy projects, the implementation of the smart grid, compliance with standards, and the introduction of energy conservation measures, including demand-side management activities, are necessary.

We believe that electricity generation, transmission, and distribution systems are the riskiest in terms of energy security along the electricity industry's supply chain. Our rationale is supported by the fact that, even if a nation is not self-sufficient in terms of energy resources because it lacks the necessary energy commodities to produce electricity, it will require the development of productive facilities based on fossil fuels or nuclear power. Furthermore, even if there is a case where a state lacks both energy resources and generation facilities, it must develop robust electrical capacities in its electricity transmission and distribution system to import electricity from neighboring nations.

7.5 From the Model

We have constructed a security index method for measuring supply security in the electricity industry's supply chain. We have supported our research by considering technical issues, standards, and concepts from economic theory that were previously avoided because of a lack of consensus between scholars and technicians in the electricity industry. Our decision fit the security considerations because it prescribes basic functions and achieves safety levels by mitigating risks. The index model can be applied in the supply chain of other business areas in the energy industry, as in the cases of hydrocarbons and minerals. The success of this model depends in its ability to define clearly the threats affecting security and their importance in light of the available literature and data.

Our method is a more value-objective-oriented instrument than others. By these means, we are able to allocate more reasonable values to evaluate both efficiencies and inefficiencies in complying with standards in certain activities of a given system. The functioning of our model depends on outlining the threats as well as accurately defining their importance in light of the literature and data. For any index model, most of the risks must be identified in the performance of the physical infrastructure. The methodology has established security levels for the overall electricity industry and at the system level.

The proposed methodology offers a more comprehensive quantitative and graphical model to understand energy security in the electricity industry. This model can be employed in future analyses in other sub-sectors of the energy industry. Our methodology is not limited to one specific geographical context or to the use a specific number of indicators. Using this methodology, development areas can be identified in terms of energy projects as well as socio-economic activities. The study of the electricity industry in terms of energy security can provide insights about threats that need to be mitigated in a given system, and these can represent business opportunities for suppliers of equipment and services associated with the operational performance of that system.

Finally, much further research needs to be done in this field at the country level. We believe that the index model needs to be carried out on the demand side. Based on data availability, a new index as part of the industry's supply chain might account for indicators such as electricity service price stability, the average service availability index (ASAI), the customer average interruption duration index (CAIDI), the customer average interruption frequency index (CAIFI), and the electricity savings by sector (Yeddanapudi 2005) to assess the supply security in the industry's downstream systems. In addition, an econometric assessment is vital to identify external factors from the industry's macro-environment that can affect the supply security of energy commodities.

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Appendixes

Appendix 1: Data sources

Country	*Ministry Related with Energy Issues*	*Regulatory Agency*	*System or Market Operator*
México	Secretaría de Energía	Comisión Reguladora de Energía	Comisión Federal de Electricidad
	http://www.sener.gob.mx/	http://www.cre.gob.mx/	http://www.cfe.gob.mx/
Guatemala	Ministerio de Energía y Minas	Comisión Nacional de Energía Eléctrica	Administrador del Mercado Mayorista
	http://www.mem.gob.gt/	http://www.cnee.gob.gt/	http://amm.org.gt
El Salvador	Ministerio de Economía	Superintendencia General de Electricidad y Telecomunicaciones	Unidad de Transacciones S.A. de C.V.
	http://www.minec.gob.sv/	http://www.siget.gob.sv/	http://www.ut.com.sv/
Honduras	Secretaría de Recursos Naturales y Ambiente	Comisión Nacional de Energía	Empresa Nacional de Energía Eléctrica
	http://www.serna.gob.hn/	http://www.cne.gob.hn/	http://www.enee.hn/
Nicaragua	Ministerio de Energía y Minas	Instituto Nicaragüense de Energía	Centro Nacional de Despacho de Carga
	http:// www.mem.gob.ni/	http://www.ine.gob.ni/	http://www.cndc.org.ni/
Costa Rica	Ministerio Ambiente, Energía y Telecomunicaciones	Autoridad Reguladora de los Servicios Públicos	Instituto Costarricense de Electricidad
	http://www.minae.go.cr/	http://www.aresep.go.cr	http://www.grupoice.com/wps/portal/
Panamá	Secretaría Nacional de Energía	Autoridad Nacional de los Servicios Públicos	Empresa de Transmisión Eléctrica – Centro Nacional de Despacho
	http://www.energia.gob.pa/	http://www.asep.gob.pa/	http://www.etesa.com.pa/
			http://www.cnd.com.pa/
Colombia	Ministerio de Minas y Energía	Comisión de Regulación de Energía y Gas	XM
	http://www.minminas.gov.co/	http://www.creg.gov.co/html/i_portals/index.php	http://www.xm.com.co/Pages/Home.aspx
Ecuador	Ministerio de Electricidad y Energía Renovable	Consejo Nacional de Electricidad	Centro Nacional de Control de Energía
	http://www.energia.gob.ec/	http://www.conelec.gob.ec/	http://www.cenace.org.ec/
Perú	Ministerio de Energía y Minas	Organismo Supervisor de la Inversión en Energía y Minería	Comité de Organización Económica del Sistema Interconectado Nacional
	http://www.minem.gob.pe/	http:// www.osinerg.gob.pe/	http://www.coes.org.pe/wcoes/inicio.aspx
Chile	Ministerio de Energía	Comisión Nacional de Energía	Centro de Despacho Económico de Carga Sistema Interconectado Central
	http://www.minenergia.cl/	http://www.cne.cl/	https://www.cdec-sic.cl/index_en.php
Argentina	Secretaría de Energía	Ente Nacional Regulador de la Electricidad	
	http://energia3.mecon.gov.ar/home/	http://www.enre.gov.ar/	http://portalweb.cammesa.com/default.aspx
		Other Data Sources Consulted Regarding Economic and Energy Issues	
Regional	Comisión Económica para América Latina y el Caribe	Asociación Latinoamericana de Integración	Sistema de Interconexión Eléctrica de los Países de América Central
	http:// www.eclac.org/	http://www.aladi.org/	http://www.eprsiepac.com/

Appendix 2: Energy Resources Potential

Countries with Potential for Production of Renewable Energy Resources												
Source / Country	***MEX***	***GTM***	***ELS***	***HND***	***NIC***	***CRC***	***PNM***	***COL***	***ECU***	***PER***	***CHL***	***ARG***
Hydro	●	●	□	●	●	•	•	●	●	●	●	●
Solar	●	●	□	●	●	•	•	●	●	●	●	●
Geothermal	●	•	•	□	•	•	□	□	□	□	●	□
Wind	•	□	□	□	•	•	□	•	□	•	•	•
Biomasses	•	□	□	□	□	□	□	•	•	•	□	•

Latin American Energy Organization (OLADE) - Statistics Report (2012)

- Hydroelectricity

High potential	●	Over 3,001 MW
Medium potential	•	Till 3,000 MW
Low potential	□	Below 500 MW
Lack of potential	○	0 MW

Countries with Potential for the Production of Non-Renewable Energy Resources												
Source / Country	***MEX***	***GTM***	***ELS***	***HND***	***NIC***	***CRC***	***PNM***	***COL***	***ECU***	***PER***	***CHL***	***ARG***
LNG	●	□	○	○	○	○	○	◍	◍	□	□	●
SNG	●	□	□	□	□	□	□	●	□	□	□	●
Coal	□	○	○	○	○	□	□	●	□	□	□	□
Oil	●	□	○	○	○	○	○	◍	◍	□	□	◍

Latin American Energy Organization (OLADE) - Statistics Report (2012)

- Oil

High potential	●	Over15,001 Mbbl of oil in proven reserves
Medium potential	◍	Below 15,000 Mbbl of oil in proven reserves
Low potential	□	Till 5,000 Mbbl of oil in proven reserves
Lack of potential	○	0 Mbbl of oil in proven reserves

- Gas

High potential	●	Over 501 Gm^3 in proven reserves
Medium potential	◍	Below 500 Gm^3 in proven reserves
Low potential	□	Till 100 Gm^3 in proven reserves
Lack of potential	○	0 Gm^3 in proven reserves

- Coal

High potential	●	Over 3,001 Mt in proven reserves
Medium potential	◍	Below 3,000 Mt in proven reserves
Low potential	□	Till 100 Mt in proven reserves
Lack of potential	○	0 Mt in proven reserves

Appendix 3: Activities to Improve Security of Supply in T&D System and Support Smart Grid Implementation

Activities to Improve Security of Supply in T&D System and Support Smart Grid Implementation												
Activity/Country	***MEX***	***GTM***	***ELS***	***HND***	***NIC***	***CRC***	***PNM***	***COL***	***ECU***	***PER***	***CHL***	***ARG***
Transformers in substations	□	●	□	●	●	□	●	□	●	□	□	□
Power Rectifier	□	●	□	●	●	□	●	□	●	□	□	□
Power Inverter	□	●	□	●	●	□	●	□	●	□	□	□
Power Capacitors	□	●	□	●	●	□	●	□	●	□	□	□
Power Reactor	□	●	□	●	●	□	●	□	●	□	□	□
Gas insulated switch disconnector	□	●	□	●	●	□	●	□	●	□	□	□
Power Condensers	□	●	□	●	●	□	●	□	●	□	□	□
Harmonic filters	□	●	□	●	●	□	●	□	●	□	□	□
Circuit breakers	□	●	□	●	●	□	●	□	●	□	□	□
Reclosers	□	●	□	●	●	□	●	□	●	□	□	□
Meters (delivering points)	□	●	□	●	●	□	●	□	●	□	□	□
Fuses	□	●	□	●	●	□	●	□	●	□	□	□
Transformers in overhead lines	□	●	□	●	●	□	●	□	●	□	□	□
Wires' Size	□	●	□	●	●	□	●	□	●	□	□	□
Electricity poles or structures	□	•	□	•	•	□	•	□	•	□	□	□
Meters (consumers)	●	●	●	●	●	●	●	●	●	●	●	●
Billing system	●	●	●	●	●	●	●	●	●	●	●	●

Requires implementation in the short-term (1-2 years)	□
Requires implementation in the medium-term (3-4 years)	●
Requires implementation in the long-term (over 5 years)	•

Appendix 4: Security of Supply Performance by Country

Appendix 4.1: RSSSI's Ranking by Country

Energy Resources System Security of Supply Performance												
#	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1º	COL	CRC	COL	CHL	CHL	CHL	CHL	CHL	CHL	CHL	CHL	CHL
2º	CRC	COL	CRC	COL	COL	COL	COL	COL	COL	COL	COL	PER
3º	MEX	PER	ECU	CRC	CRC	CRC	CRC	CRC	CRC	CRC	CRC	COL
4º	ECU	CHL	CHL	PER	PER	PER	PER	ECU	ECU	ECU	PER	ELS
5º	PER	ECU	MEX	ECU	ARG	ECU	MEX	MEX	MEX	ELS	ELS	CRC
6º	CHL	MEX	PER	ARG	MEX	MEX	GTM	GTM	PER	PER	ECU	ECU
7º	ARG	ARG	ARG	MEX	ECU	GTM	ARG	ARG	GTM	MEX	GTM	GTM
8º	GTM	GTM	GTM	GTM	GTM	ELS	ECU	PER	ELS	ARG	MEX	MEX
9º	PNM	ELS	ELS	ELS	ELS	ARG	ELS	ELS	ARG	GTM	ARG	ARG
10º	ELS	PNM	PNM	PNM	PNM	PNM	PNM	PNM	PNM	PNM	PNM	PNM
11º	HND	HND	HND	HND	HND	NIC	HND	HND	HND	HND	HND	HND
12º	NIC	NIC	NIC	NIC	NIC	HND	NIC	NIC	NIC	NIC	NIC	NIC

●	**Most secure nations**
●	**Less secure nations**

Appendix 4.2 GSSSI's Ranking by Country

Electricity Generation System Security of Supply Performance												
#	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1º	PNM	COL	COL	COL	COL	COL	COL	COL	COL	COL	PER	COL
2º	COL	PER	PER	PER	PER	PNM	PNM	PER	PER	PER	COL	PER
3º	PER	ECU	ECU	NIC	GTM	PER	PER	PNM	PNM	ECU	GTM	ECU
4º	ECU	PNM	NIC	GTM	PNM	NIC	GTM	GTM	ECU	NIC	ECU	GTM
5º	GTM	GTM	GTM	ECU	ECU	GTM	NIC	NIC	GTM	PNM	NIC	NIC
6º	NIC	NIC	PNM	PNM	NIC	HND	ECU	ECU	NIC	GTM	PNM	CHL
7º	CHL	CHL	CHL	CHL	CHL	CHL	HND	HND	HND	CHL	CHL	PNM
8º	MEX	MEX	MEX	MEX	MEX	MEX	CHL	CHL	CHL	HND	HND	CRC
9º	CRC	CRC	CRC	CRC	CRC	ECU	MEX	MEX	MEX	MEX	CRC	MEX
10º	ARG	ARG	ELS	ARG	ARG	CRC	ARG	ELS	CRC	CRC	MEX	ELS
11º	HND	HND	HND	HND	HND	ELS	ELS	CRC	ELS	ELS	ELS	ARG
12º	ELS	ELS	ARG	ELS	ELS	ARG	CRC	ARG	ARG	ARG	ARG	HND

●	**Most secure nations**
●	**Less secure nations**

Appendix 4.3 TDSSSI's Ranking by Country

Electricity T&D Systems Security of Supply Performance												
#	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1º	PER	CHL	PER	PER	CHL	CHL	CHL	CHL	CHL	CHL	CHL	ECU
2º	CHL	PER	CHL	CHL	PER	PER	ARG	GTM	ARG	ARG	ECU	CHL
3º	COL	ARG	ARG	ARG	ARG	ARG	PER	ARG	GTM	GTM	GTM	GTM
4º	ELS	ELS	ELS	ELS	COL	COL	COL	COL	COL	ECU	HND	ELS
5º	ARG	COL	COL	COL	ELS	GTM	HND	HND	PNM	HND	ELS	HND
6º	CRC	CRC	CRC	CRC	CRC	ELS	CRC	ELS	ELS	ELS	PNM	PNM
7º	ECU	ECU	ECU	GTM	GTM	CRC	GTM	ECU	HND	PNM	CRC	CRC
8º	GTM	GTM	GTM	ECU	PNM	PNM	PNM	PNM	ECU	COL	COL	ARG
9º	MEX	PNM	PNM	PNM	ECU	HND	ECU	PER	CRC	CRC	ARG	MEX
10º	HND	MEX	MEX	MEX	HND	ECU	ELS	CRC	PER	PER	MEX	COL
11º	PNM	HND	HND	HND	MEX	MEX	MEX	MEX	MEX	MEX	PER	NIC
12º	NIC	NIC	NIC	NIC	NIC	NIC	NIC	NIC	NIC	NIC	NIC	PER

●	**Most secure nations**
●	**Less secure nations**

Appendix 4.4 EISSI's Ranking by Country

Electricity Industry Security of Supply Performance												
#	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1º	COL	COL	COL	COL	COL	COL	CHL	CHL	CHL	CHL	CHL	CHL
2º	PER	PER	PER	CHL	PER	PER	COL	COL	COL	COL	COL	COL
3º	ECU	ECU	ECU	PER	CHL	CHL	PER	PER	PER	ECU	GTM	PER
4º	PNM	CHL	CHL	ECU	CRC	PNM	PNM	PNM	ECU	PER	ECU	ECU
5º	CHL	GTM	CRC	GTM	GTM	CRC	GTM	GTM	PNM	GTM	PER	GTM
6º	CRC	CRC	GTM	CRC	ECU	GTM	CRC	ECU	GTM	CRC	CRC	ELS
7º	MEX	PNM	PNM	PNM	PNM	ECU	ARG	CRC	CRC	ELS	PNM	CRC
8º	GTM	ARG	NIC	NIC	ARG	ARG	ECU	HND	ARG	PNM	ELS	PNM
9º	ARG	NIC	MEX	ARG	MEX	ELS	HND	ELS	ELS	HND	HND	NIC
10º	NIC	ELS	ARG	MEX	NIC	NIC	ELS	ARG	HND	ARG	NIC	MEX
11º	ELS	MEX	ELS	ELS	ELS	HND	MEX	MEX	MEX	NIC	MEX	HND
12º	HND	HND	HND	HND	HND	MEX	NIC	NIC	NIC	MEX	ARG	ARG

●	**Most secure nations**
●	**Less secure nations**

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제 목

중남미 12개국의 전력에너지확보 및 평가지표에 관한 연구

초록

중남미 지역은 풍부한 지하자원 및 천애의 자연환경으로 잘 알려져 있으며, 국가간 경제교류가 활발이 이루어지고 있어 국제 경제의 전략 지역으로 성장하고 있다. 또한, 강력한 민주화 정책, 지역통합, 책임있는 거시경제의 채택, 화폐 및 회계의 정책적 지원과 자유무역과 민간부분의 적극적인 참여로 상당한 수준의 사회-경제적으로 거시적인 경제발전을 이루었으며, 최근의 국제 금융위기에도 불구하고 지속적인 경제성장을 보이고 있다.

OECD 국가인 멕시코와 칠레, 그 인접 개발도상국인 콜롬비아와 코스타리카의 활발한 경제교류에서 알 수 있듯이, 중남미지역의 특별한 지정학적 위치 및 다양성으로 인하여 동남아시아, 중앙아시아, 중동 및 아프리카 지역과는 차별화 되어, 경제 및 에너지분야 이슈의 연구에 있어, 보다 가치 있는 성과를 얻을 것으로 기대한다.

이러한 상황과 유리한 조건들을 바탕으로 중남미 국가간 협력을 통한 투자확대로, 세계에서 가장 큰 경제지역을 지향하고 있으나, 전력산업이 경제성장을 뒷받침하지 못하고 있는 상황이고, 이는 잘 알려져 있는 바와 같이, 대부분의 국가들은 지하자원 분야뿐 아니라 전력생산 분야의 에너지프로젝트개발을 위한 큰 잠재능력은 가지고는 있지만, 전력산업이 빠른 경제성장 및 새로운 사업모델개발을 뒷받침하지 못하고 있기 때문이며, 이러한 전력확보의 불확실성은 전력산업의 민영화 이후 더욱 두드러지게 나타나고 있다.

본 논문에서는, 중남미 12개국(멕시코, 과테말라, 엘살바도르, 온두라스, 니카라과, 코스타리카, 파나마, 콜롬비아, 에콰도르, 페루, 칠레 그리고 아르헨티나)의 전력산업을 평가하는데 초점을 맞추고, 안정적 전력산업의 평가 지표 및 조건에 대한 분석을 하였다. 본 연구에 사용된 전력산업 지표는 경제학 및 전력분야에서 국제적으로 통용되는 가장 보편적인 기준을 바탕으로, 전력산업에 영향을 주는 지표 분석을 수행하였으며, 지표간 상호연계성을 가지는 단순 및 합성 지표를 활용하여 국가의 전력산업을 평가하였다.

이러한 주요 영향요인 분석과정을 거쳐, 전력산업에 영향을 미치는 내/외부적 상황 연구를 위한, ‘안정적 전력공급 평가지표를

제안하였으며, 본 논문에서 제안한 지표를 통하여 중남미 국가들을 분석한 결과, 칠레, 콜롬비아, 페루, 에콰도르는 양호한 평가를 받았으며, 대부분의 남미지역 국가들은 중-상위 범위의 수준에 있음을 확인하였다. 본 논문이 제안한 분석기법의 신뢰성을 저하시키는 원인으로는 전력산업을 구성하는 다양한 전력시스템에 기인한다.

안정적 전력확보는 천연 지하자원뿐 아니라 전력인프라도 크게 영향을 미친다. 그러나, 지정학적으로 천연 지하자원이 부족한 국가인 경우는, 3가지 경우에 대한 조사를 병행하였으며, 이러한 국가들은 신-재생 에너지에 기반한 전원공급원 다양화(Energy Mix)로 전력공급능력을 개선시킬 수 있다. 발전, 송전, 배전에 이르는 전력시스템의 운영 능력은 전력 인프라 및 품질관리 능력에 크게 영향을 받으며, 이러한 품질관리 기준을 만족하지 않을 경우, 전력시스템 붕괴 및 전력확보의 불확실성은 증가하게 된다.

본 논문에서 연구한 중남미 국가들의 안정적 전력공급능력 확보는 내/외부적인 요소에 영향을 받기 쉬우므로, 정부가 혁신적인 결정을 하는 중요한 역할을 해줄 것을 제안하며, 또한, 안정적 전력공급 운영능력 향상을 위한 장려정책 등의 지원이 동반 되어야 한다. 재화의 수출 및 자원개발에 있어, 정확한 사업관리 시스템구축이 필요하며, 사회-경제적 요구에 부흥하는 견고한 전력인프라 확충 및 충분한 지하자원에 기반한 새로운 사업모델 및 대규모 전력프로젝트 개발을 위한 적극적인 투자지원정책 및 투자를 유도하면서 전력인프라를 확충하기 위한 적정한 전력시장가격의 형성되어야 한다. 마지막으로 에너지보호, 수요관리 프로그램 및 안정적 전력공급 수준을 개선할 수 있는 단계별 프로그램 수립 등이 필요하다.

주요어: 에너지확보, 전력산업 공급체인, 안정적 전력확보 지표, 합성지표, 전력기반시설.

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